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K. Jones

OPERATION GREENHOUSE

SCIENTIFIC DIRECTOR'S REPORT
ANNEX 6.6
EVALUATION OF FILTER MATERIAL

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NUCLEAR EXPLOSIONS
1951

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Defense Nuclear Agency
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Alexandria, Virginia 22310-3398

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12 July 1995

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Evaluation of Filter Material

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EVALUATION OF FILTER MATERIAL

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of the
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January 1952

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Abstract

Four types of standard and developmental filter materials used in individual and collective-protective devices and one type of developmental filter material used for the sampling of air for particulate matter were evaluated against the contamination produced by the detonation of an atomic bomb and present in the resulting radioactive cloud. These filter materials were evaluated in multilayer pads at the standard flow-rate conditions used by the Chemical Corps in evaluation studies of filter materials. This permitted correlation of results with laboratory data.

The filter materials were evaluated in eight drones in the first three tests at altitudes ranging from 16,000 to 30,000 ft. A portion of the cloud was continuously sampled isokinetically by a probe which extended through the nose of the aircraft. The sample of the cloud passed from the probe into a plenum chamber, from which it was continuously exhausted to the exterior of the aircraft. The filter materials were located on a suitable apparatus in the plenum chamber and evaluated against contaminated air drawn from this chamber.

Analysis of the filter materials was made by counting the gross beta activity collected on successive layers of the same filter material and the efficiency of the material was calculated from the data obtained. Selected samples of the filter material were also counted to obtain a measure of the amount of alpha activity present in the cloud. Radioautographs were made of selected samples to determine the distribution of activity on the filter papers. Decay data were also taken on selected samples to determine the gross decay constant, n, in the equation $A=A_0t^n$ for activity associated with particulate material in the cloud. The average value was found to be −1.08 during the period H-hour plus 250 to 2,000 hr.

The mean efficiency of the Chemical Corps Types 6, 7, and 8 respiratory protective filter material is 99.7 to 99.9 per cent against the gross particulate contamination. This is within the limits of accuracy of the methods used to determine efficiency. The mean efficiency of Type 5 filter material is 84.1 per cent and that of the polyfiber air-sampling filter material is 74.3 per cent. These data correlate closely with laboratory data and indicate that the efficiency against a high-intensity radioactive aerosol cloud is comparable to that measured by a nonradioactive laboratory test aerosol.

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Chapter [redacted]

Introduction

1.1 HISTORICAL BACKGROUND

In previous atomic weapons tests, at Alamogordo, Bikini, and Eniwetok, no evaluation was made of filter materials designed for protection of personnel against the resulting radioactive aerosol hazard. On Operation Sandstone an evaluation of Type 6 filter material as a component of the field collective protector was attempted. However, no data were obtained on the filtration efficiency of the collective protector since the structures in which they were located were damaged by the force of the detonation.[1]

Laboratory evaluation of Chemical Corps Type 6 filter material has been conducted at the Army Chemical Center against a beta-gamma radioactive aerosol of controlled particle size of 0.5 μ mass median diameter.[2] To an airborne activity level of 100 microcuries per liter of air no decrease in filtering efficiency was noted, as compared with the measured efficiency by comparable tests using nonradioactive aerosols. As the airborne activity level is increased to 4,000 microcuries per liter of air the filtering efficiency actually increases through the presence of the increased activity.[3]

However, no evaluation has been made of the filtering efficiency against radioactive aerosols of unknown particle-size distribution, such as the gross condition existing in the cloud following an atomic bomb detonation.

1.2 THEORETICAL BACKGROUND

1.2.1 Test Conditions

The standard Chemical Corps test conditions for the acceptance testing of filter material specifies that a circular disk of filter material of 100 sq cm area will be evaluated at a flow rate of 85 liters/min.[4]

However, the specifications for acceptance testing of assembled canisters call for a flow rate of 32 liters/min.[5] This latter flow rate is designed to show up, to a greater degree, any defects in the filter material.[6] Therefore, this test condition was chosen as the most stringent. The linear flow rate through the filter sheet corresponding to this volume flow rate is 320 cm/min.

1.2.2 Isokinetic Sampling

For the evaluation of filter paper it was considered necessary that a representative sample of the cloud be conducted into the chamber from which the filter material sampler drew the contamination. For this purpose a probe extended beyond the nose of the aircraft into free air. To ensure that a representative sample of the cloud was obtained under the high-velocity sampling conditions imposed by the movement of the aircraft, it was consid-

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[1] B. Siegel, CDR H. L. Andrews, and R. E. Murphy, "Efficiency of Field Collective Protector," Sandstone Report 30, Part V of Project 7.1-17/RS(CC-8), E24R3.

[2] E. H. Engquist and J. J. Mahoney, "Development of the Radioactive Sodium Iodide Test for Filter Material," Chemical Corps TCR 60.

[3] E. H. Engquist and J. J. Mahoney, "Filter Material Efficiency Against High Levels of Airborne Radioactive Contamination," Chemical Corps Technical Report CRLR 14.

[4] Chemical Corps Specification No. 197-54-303D.

[5] Chemical Corps Specification No. MIL-C-10116.

[6] J. Goldfield, Capt. A. W. Plummer, and Capt. D. W. Beaumont, "Increase in Pinhole Detection by the MIT-E1 Meter," Chemical Corps MIT-MR-167.

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ered important that isokinetic sampling conditions be [redacted] probe. [redacted] pressed as follows:

$$\frac{V_{\text{probe}}}{V_{\text{air stream}}}=1 \tag{1.1}$$

where

V_{probe}=linear velocity of air stream in the probe inlet

$V_{\text{air stream}}$=linear velocity of air stream external to the probe, perpendicular to the plane of the probe inlet.

The magnitude of the error in representative sampling that results from deviation from the ideal condition is a complex function of air velocity, particle size, particle-size distribution, density of the particles relative to the medium, viscosity of the medium, etc. It is beyond the scope of this report to calculate this effect. However, it can be stated that for conditions in which the ratio is greater than 1, small particle sizes are selectively sampled into the probe, and for ratios less than 1, large particles are selectively sampled. A more complete discussion of this effect is given in the report on cloud particle size and distribution.[7]

1.2.3 Determination of Efficiency

Multilayer pads of filter material can be used to determine the efficiency of a single layer of filter material in the following manner:

Designate succeeding layers of the same filter material in a pad through which the contaminated air passes 1, 2, 3, . . ., n. Each filter sheet is known to remove a certain fraction of the airborne contamination. The efficiency of the first layer can be calculated by the following formula:

$$\text{Efficiency}_1=\frac{\text{d/m}_1}{\text{d/m}_1+\text{d/m}_2+\text{d/m}_3+\ldots+\text{d/m}_n} \tag{1.2}$$

where d/m is the counting rate of activity collected, corrected to identical geometry conditions. This formula holds so long as the penetration of the last layer in a pad is negligible. A similar calculation can be made of the efficiency of the second layer by the following formula:

$$\text{Efficiency}_2=\frac{\text{d/m}_2}{\text{d/m}_2+\text{d/m}_3+\ldots+\text{d/m}_n}.$$

Per cent penetration is then defined by the following formula:

$$\text{Per cent penetration}=100(1-\text{efficiency}). \tag{1.3}$$

The data can also be represented graphically if the penetration data, corrected to identical geometry conditions, are plotted on semilogarithmic paper as shown in Fig. 1.1. The nonuniformity of the cloud or the selective filtration of the various particle sizes in the gross contaminant are indicated by the nonlinearity of the graph.

However, there is a limitation on obtaining high accuracy with this method. In the case of various efficient filter materials, such as Chemical Corps Types 6, 7, and 8, the use of the efficiency formula given above involves the division of two large numbers almost equal in size. That is, the activity of the second and succeeding layers is very small in comparison with that of the first layer. Under these conditions, the method is limited in the number of significant figures to which the efficiency of the first layer can be determined, and any errors in technique resulting in minor contamination of the second and succeeding layers result in magnification of the error on observed efficiency of the first layer.

[7] E. H. Engquist, "Cloud Phenomena: Study of Particulate and Gaseous Matter," Greenhouse Report, Annex 6.1.

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Chapter 2

Preoperational Development

2.1 APPARATUS

2.1.1 Description

A single sampling unit was designed upon which all five types of filter material could be evaluated simultaneously. Essentially, this unit comprised a cubical sheet-metal box. On five sides of the cube the multilayer pads of filter material were located, with the sixth side connected to a motor-blower unit connected as a vacuum pump to provide flow through the multilayer pads. The diameter of the open face was approximately 4.45 in., so that 100 sq cm of filter material were evaluated on each face. Inasmuch as the total resistance of the various multilayer pads being evaluated was not equal, it was necessary to have individual orifices located to control the flow through each individual pad. This was achieved by the use of a honeycomb construction inside the cube upon which the pads were located. With this design it was possible to adjust orifice sizes so that the total resistance of each matched orifice plus multilayer filter pad was the same for all five pads evaluated on a single unit. Following the matching of orifices, the total flow of the single motor blower was adjusted to deliver 160 liters/min of air, to provide 32 liters/min through each of the five filter pads. The filter unit without filter pads is shown in Fig. 2.1. The assembled unit with filter pads in place is shown in Fig. 2.2. Construction details are given on Chemical Corps Drawing A124–4–71.

2.1.2 Installation in Aircraft

The filter sampling unit was installed in the wall of a plenum chamber through which a sample of the cloud was continuously passed at a flow rate of 509 to 760 liters/min of free air, depending on the altitude. A probe extended through the left-hand gun port of the nose of the aircraft into free air beyond the nose, and was long enough to extend into air undisturbed by the forward motion of the aircraft. The probe and exhaust-tube installation is shown in Fig. 2.3. In exhaustive flight tests at Eglin Air Force Base, flutter strips were mounted on a crossrod at 90° to the axis of the probe. By observation of these flutter strips under flight conditions at 150 mph indicated air speed, it was ascertained that the motion of the air in the vicinity of the probe inlet was parallel to the axis of the probe. A static tube was located above the probe to determine free-air static pressure for use in adjustment for isokinetic sampling conditions.

The method of determination of equivalent velocity conditions is treated by Elliot Reid in the report on the development of the snap sampler.[1] A static tap was located in the probe inlet and isokinetic flow conditions were obtained by adjusting the flow through the probe inlet so that the differential between free-air static pressure and probe-inlet static pressure was zero. A valve located in the exhaust line from the plenum chamber was adjusted to obtain these isokinetic conditions. The exhaust valve for adjustment is shown in Fig. 2.4, with the filter-material sampler shown assembled in the plenum chamber.

The sampling system is shown diagrammatically in Fig. 2.5. Inasmuch as the sampling was conducted from a chamber as shown in this figure, it was necessary to confirm ex-

[1] E. H. Engquist, "Cloud Phenomena: Study of Particulate and Gaseous Matter," Greenhouse Report, Annex 6.1, Appendix A.

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[redacted]

perimentally that the sampling was not a function of position on the filter-material sampler. In the final design of the sampling apparatus the various faces presented different geometries to the general direction of flow of contaminated air in the plenum chamber. The plenum chamber had been designed so that the calculated Reynolds number would not exceed 500 for air sampled by the probe at 150 mph indicated air speed. To check this experimentally, a test set up utilizing dioctylphthalate smoke was used as outlined in Sec. 2.3.2. Through this experiment it was determined that the sampling was independent of position of the apparatus. Data to support this result are given in Sec. 2.3.2, Table 2.3.

2.2 CHARACTERISTICS OF FILTER MATERIAL

Of the five types of filter material evaluated, four were standard or developmental military respiratory filter materials used in individual or collective protectors for aerosol protection. The fifth filter material was developed by the Chemical Corps for the U. S. Air Force for use in sampling air for radioactive contamination in connection with long-range detection of atomic bomb detonations.

The characteristics of the filter materials evaluated are given in Table 2.1, including composition, resistance, and penetration data. The methylene blue test is the standard Chemical Corps solid aerosol test, with an average particle size of approximately 0.8 μ in diameter.[2] The dioctylphthalate is the standard liquid aerosol test with an average particle size of approximately 0.3 μ diameter.[3]

In order to obtain sufficient data upon which to calculate efficiencies and to ensure negligible penetration of the n-th sheet, it was determined that three layers of Types 6, 7, and 8 and five layers of Type 5 and polyfiber filter material would comprise a multilayer pad for evaluation purposes. The calculated penetration of the final layer, based on the dioctyl-

[2] Long and Siegel, "Development of Methylene Blue Test Apparatus, E5R2," Chemical Corps TDMR 1113.

[3] Dinius and Plummer, "Development of the DOP Smoke Penetration Test for Filter Material," Chemical Corps MIT–MR–52.

TABLE 2.1 CHARACTERISTICS OF FILTER MATERIALS

TYPE	COMPOSITION		RESISTANCE ($mm\ H_2O$) (32 liters/min)	PENETRATION DATA	
	Material	Per Cent		Methylene Blue (per cent)	Dioctylphthalate (per cent)
5	Cotton Flock	58	4.5	10	32
	Viscose Flock	34			
	Hemp or Caroa	5			
	Crocidolite Asbestos	3			
6	Causticized Esparto	48	41	<0.005	0.037
	Cotton Flock	26			
	Hemp	6			
	Crocidolite Asbestos	20			
7	Causticized Viscose	80	38	<0.005	0.016
	Crocidolite Asbestos	20			
8	Causticized Viscose	56	43	<0.005	0.040
	"AA" Fiberglas	38			
	Chrysotile Asbestos	6			
PF	Polystyrene	95	3	10	60
	Polyvinyl Butyral (binder)	5			

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phthalate and methylene blue test data, is given in Table 2.2.

TABLE 2.2 CALCULATED PENETRATION OF MULTILAYER TEST PAD

TYPE	PER CENT PENETRATION	
	Methylene Blue	Dioctylphthalate
5	<0.001	0.35
6	<0.001	<0.001
7	<0.001	<0.001
8	<0.001	<0.001
PF[a]	<0.001	7.8

[a] Polyfiber.

2.3 PREOPERATIONAL EVALUATION

2.3.1 Flow Calibration

Calibration of flows through individual sections of the filter-material sampler and adjustment of orifices were carried out with the equipment shown in Fig. 2.6. Five orifices of identical construction and characteristics were attached over the five multilayer pads of filter material and the pressure drop across these orifices was measured by a standard gas meter, with the pump drawing 160 liters/min through the entire apparatus. The inner matching orifices for the multilayer pads were then adjusted in size until the same flow was metered through each of the outer calibration orifices. Inasmuch as these orifices all had the same resistance they added equally to the sum of the filter pad and matching orifice resistance. Removal of the calibration orifices thus did not change the ratio of flows through the five pads. A readjustment was made on the motor speed of the fan to compensate for the removal of the additional resistance of the calibration orifices. The total volume of air handled was reset to 160 liters/min. The orifices were not changed when filter pads were changed in the on-site operations. Thus the flow through individual pads varied approximately ±10 per cent from the mean value of 32 liters/min through fluctuations in the resistance of the materials tested. This was considered adequate when all operational variables were considered. A detailed discussion is given in Sec. 3.1.

2.3.2 Evaluation with Dioctylphthalate Test Aerosol

In order to determine that each pad location would obtain a representative sample of the contaminated aerosol when the sampler was located in the plenum chamber, a test was conducted with dioctylphthalate test aerosol. This was considered necessary inasmuch as each pad position on the filter-material sampler presented a different frontal face to the direction of flow of air through the plenum chamber. The test was accomplished in the following manner. Four of the five pad positions were blocked off to airtightness, and a multilayer pad of Type 5 filter material was assembled on the remaining position. The sampler was assembled in the plenum chamber, and DOP test smoke was passed through the probe and plenum at a volume flow rate of 509 liters/min, corresponding to the flow resulting from isokinetic sampling at ground level at an aircraft speed of 150 mph. This was repeated for all positions, the single pad being assembled on one face, and the remaining four faces being closed off to airtightness. Two runs were made for each position, using a multilayer pad of four layers. The average penetration results are shown in Table 2.3. These data indicate that negligible selective sampling took place as a function of position on the sampler relative to the motion of air through the plenum chamber.

TABLE 2.3 EVALUATION OF FILTER-MATERIAL INSTALLATION IN PLENUM CHAMBER

FACE OF CUBE ON WHICH MULTILAYER PAD WAS LOCATED[a]	DIOCTYLPHTHALATE PENETRATION (per cent)
Front	0.36
Back	0.36
Vertical	0.36
Horizontal (top)	0.44
Horizontal (bottom)	0.31

[a] The direction of air flow through the plenum chamber was at 90° to the face designated as the Front Face, so that this filter pad presented a frontal area of 100 sq cm. The air flow then passed around the sampler, parallel to the vertical and horizontal faces.

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2.3.3 Test with Radioactive Glass Aerosol

This study was conducted in connection with an over-all evaluation of the sampling system for the purposes of this project and Greenhouse Project 6.1.[4]

A sample of glass spheres in the general size range of 0 to 20 μ was obtained from the Oak Ridge National Laboratory. This sample was separated by air elutriation into three size fractions 0 to 3, 3 to 6, and 6 to 12 μ. These samples were then placed in a solution of $iodine^{131}$ for contamination by absorption of the radioactive agent. Following contamination they were thoroughly rinsed by repeated washing with distilled water. In this manner, only "fixed" activity remained on the glass spheres. An aqueous dispersion, 1 per cent concentration by weight, was then made up of each fraction. This material was atomized, dried, and mixed into the main air stream passing through the probe and plenum chamber.

Analysis of the cascade-impactor particle-size results, conducted as part of the Greenhouse Project 6.1 evaluation of this instrument, demonstrated that the initial fractionation of the glass spheres was not complete.[5] The fractions, as obtained, were not discrete, and considerable overlap occurred. This minimized the value of the test as regards determination of filter efficiency as a function of particle size.

Evaluation by this test method was further limited by the amount of activity absorbed by the glass spheres. The concentration per liter of air which could be established was insufficient for adequate evaluation of filter-material efficiency. Indicative qualitative results only were obtained as to the filter-material efficiency. These results indicated satisfactory operation of the sampling equipment and the probe and plenum chamber.

[4] E. H. Engquist, "Cloud Phenomena: Study of Particulate and Gaseous Matter," Greenhouse Report, Annex 6.1.

[5] *Ibid.*

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Chapter 3

Test Site Operations and Analytical Procedures

3.1 PARTICIPATION IN THE OPERATION

This project participated in the first three shots of the Operation Greenhouse tests. Dog Shot was detonated at 0634 hr, 8 April 1951, local time; Easy Shot at 0627 hr, 21 April 1951, local time; and George Shot at 0930 hr, 9 May 1951, local time. The approximate TNT kiloton equivalents for the three shots were: Dog, 82 kt; Easy, 47 kt; and George, 220 kt.

Twelve AEC B-17 drone aircraft were equipped with filter-material samplers and accessory equipment. Only eight aircraft were operational for any one test, flying at true altitudes of 16,000 to 30,000 ft at intervals of 2,000 ft. All aircraft except the 30,000-ft aircraft on George Shot successfully completed the mission. All the samplers in the 23 aircraft operated satisfactorily.

3.2 DRONE OPERATIONS

The drone operational data are tabulated in Tables 3.1, 3.2, and 3.3. Presented are true altitude, number of passes made by each aircraft through the cloud, time in cloud for each pass, time of cloud entry after shot for each pass, and total time that the filter-material sampler operated. These data were tabulated from the drone pilot's log. The first penetration was made, on the average, during the period of 3 to 5 min after the shot. The average time in the cloud on the first pass was approximately 30 sec, with variations from 15 to 50 sec. The second penetration was made, on the average, during the period 9¼ to 13½ min after the shot. The average time in the cloud on the second pass was approximately 40 sec, with variations from 5 to 100 sec. Three passes through the cloud were made only on Easy Shot by three aircraft, two of which passed over the cloud on the first pass at 28,000 and 30,000 ft.

3.3 SAMPLING TIME AND CONTROL

The operation of the filter-material sampler was controlled by radio signal from the mother aircraft. The sampling was started at zero hour −5 min, and generally it was stopped at approximately 5 min after the last pass through the cloud. The data on total operating time of the filter-material sampler are given in Tables 3.1, 3.2, and 3.3. The total time "ON" varied from 15½ to 41 min. Only four sampling times of the total number of 23 exceeded 24 min.

3.4 FLIGHT TEST AND CALIBRATION

3.4.1 General Discussion

In connection with the development of the sampling system for Chemical Corps equipment, of which the filter-material sampler was one unit, wind-tunnel tests of the operation of the prototype probe, plenum chamber, and exhaust system were carried out in the wind tunnel at Wright-Patterson Air Force Base, Dayton, Ohio. The results of this evaluation are outlined in detail in Greenhouse Report, Annex 6.1.[1] It was determined that the sampling system operated satisfactorily and that it would be possible to preset the flow so that isokinetic flow conditions could be obtained in the probe tip.

[1] E. H. Engquist, "Cloud Phenomena: Study of Particulate and Gaseous Matter," Greenhouse Report, Annex 6.1.

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TABLE 3.1 DRONE OPERATIONAL DATA, DOG SHOT

A/C	ALTITUDE	TOTAL TIME IN CLOUD			TIME OF CLOUD ENTRY AFTER SHOT						SAMPLING EQUIPMENT TOTAL TIME ON	
	(ft)	1st pass (sec)	2nd pass (sec)	3rd pass (sec)	1st pass (min)	1st pass (sec)	2nd pass (min)	2nd pass (sec)	3rd pass (min)	3rd pass (sec)	(min)	(sec)
L	16,000	..	45	..	3	15	12	15	..	..	19	00
K	18,000	16	25	..	4	30	17	20	..	..	24	00
J	20,000	38	30	..	3	45	11	03	..	..	21	00
E	22,000	13	15	..	3	30	9	30	..	..	22	00
D	24,000	15	20	..	3	52	10	45	..	..	41	00
B	26,000	45	..	..	3	05	..	..	..	..	31	00
C	28,000	45	20	..	4	15	10	58	..	..	18	00
A	30,000	30	20	..	3	50	10	50	..	..	19	00

TABLE 3.2 DRONE OPERATIONAL DATA, EASY SHOT

A/C	ALTITUDE	TOTAL TIME IN CLOUD			TIME OF CLOUD ENTRY AFTER SHOT						SAMPLING EQUIPMENT TOTAL TIME ON	
	(ft)	1st pass (sec)	2nd pass (sec)	3rd pass (sec)	1st pass (min)	1st pass (sec)	2nd pass (min)	2nd pass (sec)	3rd pass (min)	3rd pass (sec)	(min)	(sec)
L	16,000	20	05	..	3	25	11	40	..	..	26	00
K	18,000	..	18	19	3	50	17	20	25	10	31	00
J	20,000	60	15	..	5	00	11	45	..	..	21	00
I	22,000	15	45	..	3	30	9	15	..	..	18	00
D	24,000	25	38	..	3	50	9	50	..	..	15	30
B	26,000	20	30	..	4	30	10	50	..	..	18	30
C	28,000	..	45	45	..	..	11	05	17	45	15	00
A	30,000	..	36	02	..	..	9	21	16	05	22	07

TABLE 3.3 DRONE OPERATIONAL DATA, GEORGE SHOT

A/C	ALTITUDE	TOTAL TIME IN CLOUD		TIME OF CLOUD ENTRY AFTER SHOT				SAMPLING EQUIPMENT TOTAL TIME ON	
	(ft)	1st pass (sec)	2nd pass (sec)	1st pass (min)	1st pass (sec)	2nd pass (min)	2nd pass (sec)	(min)	(sec)
L	16,000	22	35	5	08	12	15	18	45
K	18,000	15	20	4	40	10	05	16	00
J	20,000	40	100	5	13	13	18	20	00
I	22,000	35	83	4	35	11	52	18	55
D	24,000	33	69	4	47	11	16	18	00
B	26,000	50	55	5	00	13	35	21	00
C	28,000	45	40	5	15	11	00	20	00
F[a]	30,000	..	..	..	..	..	..	..	..

[a] Did not complete the mission.

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Flight testing of the complete installation, including a prototype filter-material sampler, was conducted at Elgin Air Force Base, Florida, on a mock-up B–17 drone aircraft by Task Unit 3.4.2, Joint Task Force Three. Final testing was carried out on the 12 instrumented aircraft at the test site. Details on the calibration of the sampling system are contained in Greenhouse Report, Annex 6.1.[2]

3.4.2 Calibration of the Sampling System for Isokinetic Flow

Prior to Dog Shot, isokinetic flow calibration data were obtained on eight of the 12 aircraft. These data indicated that the exhaust valve setting was not constant among the various aircraft, and varied erratically. Examination of the installations in an effort to locate the source of this variation revealed a poor seal between the probe and plenum chamber which permitted the leakage of air from the probe into the aircraft cabin. A qualitative estimate was first made of the magnitude of this poor seal for each aircraft and then the joint was sealed with pressure-sensitive tape. The time factor prevented recalibration of the aircraft prior to Dog or between Dog and Easy Shots. Therefore, an average value was obtained for setting the exhaust valve opening by averaging the calibration results of the four aircraft which did not have a demonstrable leak prior to sealing. The average setting of the exhaust valve used was 0.090 in. greater than the closed position of the valve. It was further demonstrated that leakage occurred on some aircraft around the periphery of the gasket sealing the filter-material sampler to the plenum chamber. This leakage was eliminated between Dog and Easy Shots by minor mechanical modification of the plenum chamber. The magnitude of the error introduced by this leak on the Dog Shot results could not be estimated.

Recalibration of the Chemical Corps probes for isokinetic flow conditions was accomplished between Easy and George Shots without further modification to the equipment. The results of this recalibration of ten aircraft, when averaged, showed a setting of 0.088 in. for isokinetic conditions. This was considered satisfactory confirmation that an appreciable error was not introduced in the Dog and Easy Shot samplings by nonisokinetic conditions.

For the George Shot operational mission the actual experimentally calibrated values of the valve setting for isokinetic flow were used.

3.4.3 Filter Sampler Flow Rate vs Altitude

Sampling for this evaluation was desired at constant volume of contaminated air. For this purpose an orifice meter was used to meter the effluent air from the filter sampler. To control the sampling rate the motor-blower speed was controlled by means of a rheostat. It was necessary to calibrate this motor-blower speed as a function of altitude.

The pressure drop across an orifice will vary as the atmospheric pressure and temperature vary. Thus it was necessary to obtain a theoretical calibration curve for the filter-material-sampler orifice. This was developed as follows from the general orifice equation:[3]

$$W=Q_1\rho_a=KCYA_2\sqrt{\frac{2g_L\rho_a{}^2\Delta H_a}{1-B^4}} \qquad (3.1)$$

dividing by ρ_a (B^4 is negligible),

$$\frac{W}{\rho_a}=Q_1=KCYA_2\sqrt{2g_L\Delta H_a} \qquad (3.2)$$

from the ideal gas law $P_1V_1=\frac{W}{M}RT_1$,

$$\rho_a=\frac{W}{V}=\frac{P_1M}{RT_1} \qquad (3.3)$$

and,

$$\Delta H_a=\frac{\Delta H_{H_2O}\times\rho_{H_2O}}{\rho_a} \qquad (3.4)$$

by substituting 3.3 and 3.4 in 3.2

$$\frac{W}{\rho_a}=Q_1=KCYA_2\sqrt{2g_L\Delta H_{H_2O}\rho_{H_2O}\frac{RT}{MP}} \qquad (3.5)$$

[2] *Ibid.*

[3] John Perry, *Chemical Engineers' Handbook,* 2nd ed. (New York, McGraw-Hill Book Company, Inc., 1941), p. 848.

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where Q_1=volumetric rate of discharge at P_1 and T_1=160 liters/min
A_2=cross section of orifice (sq ft) (D_2= 0.492 in.)
ΔH=pressure drop across orifice, in.
ρ_a=density of air
g_L=local acceleration due to gravity
C=coefficient of discharge of orifice
Y=expansion factor for orifice
K=calibration constant for orifice
B=orifice diameter/pipe diameter
M=molecular weight of air
T=temperature
P=pressure
R=gas constant.

Inserting the values of the above in consistent units into Eq. 3.5, the following equation is obtained:

$$\Delta H_{H_2O}=\frac{0.33}{K^2C^2Y^2}\frac{P}{T} \tag{3.6}$$

where ΔH_{H_2O}=inches of H_2O
P=millibars
T=°K
$K^2C^2Y^2$=constant.

It was considered that the value of $K^2C^2Y^2$ could best be determined experimentally. This was carried out in the laboratory, using a standard dry test meter to measure the total flow under known conditions of temperature and pressure. The calibration curve of the orifice at sea-level temperature and pressure is given in Fig. 3.1.

The pressure differential for a flow rate of 160 liters/min, or 5.65 cfm as shown on Fig. 3.1, is 2.88 in. of water. Through an inadvertent error at the test site all the motor-blower speeds were preset to give an indicated pressure differential of 2.70 in. of water. This error resulted in a total flow of 154.4 liters/min through the sampling apparatus and an average flow rate through individual pads of 30.9 liters/min. This value is 3.4 per cent lower than the standard flow rate of 32 liters/min.

To determine the effect of pressure and temperature on the orifice reading, the pressure differential of 2.88 in. of water corresponding to the flow rate of 160 liters/min used was inserted in Eq. 3.6 with the pressure and temperature at the time of calibration of the orifice. The value of $K^2C^2Y^2$ was determined to be 0.385, and Eq. 3.6 becomes

$$\Delta H_{H_2O}=0.857\frac{P}{T}. \tag{3.7}$$

Because of the setting of the motor-blower speed for a flow of 154.4 liters/min, Eq. 3.7 was recalculated for this flow rate, and Eq. 3.8 was obtained.

$$\Delta H_{H_2O}=0.799\frac{P}{T}. \tag{3.8}$$

Using Eq. 3.8 and the actual pressure and temperature data as a function of altitude obtained by Project 4.1,[4] the graph shown in Fig. 3.2 was developed, showing the calibration value of ΔH_{H_2O} across the orifice as a function of altitude for metering a constant flow of 160 liters/min.

A calibration flight was made in which the voltage applied to the motor-blower was held constant at 23.1±0.1 v. The actual readings of ΔH_{H_2O} as a function of altitude are shown as experimental points on Fig. 3.2. Though the readings were generally 5 per cent low, these data indicate that the required motor-blower speed for rated flow of 154.4 liters/min was not a function of altitude. On the basis of these data, the voltage of each filter-material sampler was preset on the ground to obtain a required differential of 2.7 in. across the orifice meter.

Time between shots did not permit the readjustment of the individual orifices controlling the partition of flow through each pad on a sampler. The orifices used initially for Dog Shot were used throughout the entire operation. This also resulted in deviation of the actual flow rate from the ideal conditions stipulated for evaluation purposes. Based on the laboratory data on air resistance variations of filter pads taken from the same roll of paper, it was considered that the procedure of using a single set of orifice plates would not introduce more than 20 per cent error in the flow rate through each pad during the entire test operation.

[4] C. E. Anderson and P. E. Gustafson, "Cloud Physics," Greenhouse Report, Annex 4.1.

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3.5 INSTALLATION AND REMOVAL

The samplers were assembled with the filter material during the period shot—4 to shot—2 days. The assembled filter-material sampler was then installed in the aircraft on the afternoon of the second day preceding the shot. This was approximately H—36 hr. To prevent damage to the filter material through operation of the aircraft and the elements, the tip of the probe leading to the plenum chamber was sealed shut. This was opened at approximately H—12 hr when final access to the aircraft was permitted. Except on George Shot, the aircraft were not flown from this latter period prior to take-off on the actual test mission. On George Shot the aircraft were flown for final checkout during the period up to H—12 hr. During these final checkout flights the probes were sealed to prevent the passage of air through the plenum chamber. Under no conditions were the filter-material samplers operated on checkout missions prior to the actual test mission. The units were test run for less than 1 min on the day prior to the shot during the final electrical checkout of sampling equipment operation.

The installation of the filter-material sampler and plenum chamber in the aircraft is shown in Fig. 3.3. To facilitate removal of the filter-material sampler in a minimum time, the sampler was held to the plenum chamber by springs held in place by pull-wires. To remove the filter-material sampler it was necessary to detach the rubber tubing leading from the calibration orifice to the plenum exhaust box, disconnect the electrical leads from the rheostat terminals, and pull two pull-rings to free the springs. The filter sampler could then be removed from the plenum chamber.

Removal of the filter-material samplers from the aircraft was accomplished prior to aircraft decontamination during the following periods: Dog Shot + 28 to 36 hr; Easy Shot + 28 to 36 hr; and George Shot + 5 to 9 hr. Removal of the filter sampler, along with equipment from other projects in the aircraft, required approximately 3 to 5 min in the aircraft. A two-man team, consisting of a radiological safety monitor and a project representative, accomplished the removal. Two such teams were used for each shot, each team entering an average of four aircraft. No dose of radiation involved in this operation was above the 0.3 r/week.

3.6 ON-SITE HANDLING AND PROCESSING

Following removal of the filter-material samplers from the drone aircraft, they were taken to a laboratory building for disassembly, analysis, and packing for shipment to the Zone of Interior (ZI). Upon removal of the layers of filter material from the sampler they were immediately placed in plastic bags lettered to show the test, aircraft, type of filter material, and layer number in the pad as follows:

$$D-A-5-1$$

where D=first letter of test detonation code word (Dog, Easy, or George)
A=aircraft letter designation (A through L)
5=type of filter material (5, 6, 7, 8, polyfiber)
1=number of layer in pad, beginning at influent side of pad (1, 2, 3 for Types 6, 7, 8, and 1 through 5 for Types 5 and polyfiber filter material)

Two types of bags were used, polyethylene for the polyfiber filter material and vinyl for the other four types. This was necessary because of the electrostatic attraction which existed between the polyfiber filter material and the vinyl bag.

Following Dog Shot, the samples were counted for activity and decay, using a flat area flow-type probe designed by the Naval Radiological Defense Laboratory at the request of the Chemical Corps. This flat probe, utilizing argon–carbon dioxide gas, was 6 by 6 in. square so that it covered the entire active area of the filter paper. An amplifier was also provided so that the unit could be operated with a standard Nuclear Instrument and Chemical Corporation Model 162 scaler.

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The schedule for return of samples to the ZI for analysis was as follows:

TEST SHOT	LEAVE FORWARD AREA
Dog	shot + 7 days
Easy	shot + 7 days
George	shot + 31 hr

Extensive analysis was conducted on the sample at the test site following Dog Shot to obtain sufficient data on the adequacy of test procedure and a preliminary indication of the results obtained. These results were reflected in minor modifications of operational procedures on the succeeding shots. Similarly, a more limited evaluation was conducted after Easy Shot. No processing of the samples was conducted after George Shot except to pack the samples for shipment to the ZI as rapidly as possible.

Following Easy Shot it was observed that some leakage was occurring around the periphery of the test pads, so that some of the activity was by-passing the first layer of filter paper. This defect was not detected on the preliminary analysis of the Dog Shot data at the site, but was corrected for the George Shot operation by sealing the edge of the pad with plastic pressure-sensitive tape (Scotch tape). The effect of this leakage is considered in the chapter on "Discussion of Results."

3.7 ANALYSIS AT THE ARMY CHEMICAL CENTER

3.7.1 Beta-Gamma Counting

The beta-gamma counting was accomplished by means of a flat-type, gas flow, multiwire proportional probe built by the U. S. Naval Radiological Defense Laboratory. Each probe had a 5-mil aluminum window 6 in. by 6 in. A 90 per cent argon–10 per cent carbon dioxide gas mixture was used and the flow through the probe was regulated by means of an orifice and a gas pressure gauge such that the flow rate was 250 cc/min during flushing and 50 cc/min during counting. The probes were supplied with amplifiers which fed into Nuclear Instrument and Chemical Corporation Model 162 scalers.

Each probe had a beta plateau of approximately 100 v within the range of 2,300 to 2,500 v. There was a variation in plateau from probe to probe, and to avoid a correction factor for this variation, the counting voltage was set to detect a predetermined counting rate when the standard beta sample was used. It was necessary to determine the plateau after each change of gas supply, at the beginning of each day of counting, and whenever a change occurred in the background counting rate.

Two correction factors had to be determined for each probe, namely, for the geometry due to sample distance from the probe window, and for coincidence loss.

Each probe was mounted on a stage which had shelves at five distances from it. The counting rates of a series of samples with a specific activity range of 1,000 to 70,000 c/m were determined on each shelf with the result that the relationship between shelves was found to be linear and independent of activity. Thus, a simple ratio could be used to make geometry corrections. In the case of loss due to coincidence (resolving time equals approximately 2×10^{-7} sec) the relationship between samples of different specific activity was not linear. Therefore, corrections had to be made independently for each counting rate.

3.7.2 Alpha Counting

The filter-material samples were counted for alpha activity on a General Electric Scintillation Counter, Cat. No. 9747109G1. The phosphor was silver-activated zinc sulfide mounted on lucite. The assembly utilized an RCA 5819 photomultiplier tube with a cathode-follower preamplifier and was coupled to the G-M input of a Nuclear Instrument and Chemical Co. Model 162 scaler with an operating voltage of 1,020 v. According to the manufacturer's specifications, the resolving time of the phototube and preamplifier is approximately 5 μsec. Alpha background was quite constant at 12 c/hr.

In order to meet requirements set by the design of the instrument, it was necessary to cut circles 1.5 in. in diameter from the filter-material samples. The stage of the counter

assembly was covered with a 5-mil polyethylene sheet to avoid contamination problems. In order to ensure constant geometry as close as possible to the phosphor, regardless of the thickness of the filter material and without danger of contamination of the phosphor, an iron ring, 2.24 in. OD, 1.50 in. ID, and 0.033 in. thick was placed on top of the sample. After the sample had been clamped in place under the phosphor, the stage was elevated by means of a screw at the bottom until the iron ring made contact with the frame supporting the phosphor.

3.7.3 Radioautography

The purpose of radioautographing the filter papers was twofold: (1) to determine the uniformity of deposition of active particles on each sheet of filter paper, and (2) to determine the degree of leakage of contaminated air through the periphery of the pads.

The film used in this study was Du Pont dosimeter film Type 552 with sheets 11.75 in. square. A single sheet of film was exposed inside of a light-tight double envelope. The processing of the films was carried out as follows: (1) developed in Du Pont X-ray developer for 3 min, (2) washed in running water for a few seconds, (3) rinsed in acetic acid hardener solution for 15 sec, (4) fixed in a bath of Du Pont X-ray fixer for 2 min, (5) fixed in a second bath of Du Pont X-ray fixer for 4 min, and (6) washed for 45 min. in running water. Development was conducted under constant temperature conditions.

Prior to exposure the filter papers were arranged in groups of activity by monitoring with a Beckman MX–5 beta-gamma survey meter. Beta-gamma activity measured on the surface of the papers ranged from background to 17 mr/hr. The films were exposed to the filter papers for the period of time necessary to obtain a total exposure of 800 to 1,000 mr. For papers reading greater than 1 mr/hr the exposure ranged from 3 to 32 days. For papers with activity less than 1 mr/hr the exposure period was 32 to 39 days. All available first layers in a pad of Types 5, 6, 7, and 8 and polyfiber filter material were radioautographed. In addition, all layers of the Type 5 and 6 polyfiber filter material were radioautographed. For selected papers, radioautographs were made of the top and bottom of the filter paper.

To ensure intimate and uniform contact between the filter papers and the film, boards were laid across the film packets after they were placed on the filter papers. These were weighted down with lead bricks.

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Chapter 4

Test Results

4.1 FILTER EFFICIENCY, FIRST LAYER

The most accurate efficiency calculation can be made for the first layer in a test pad. The efficiency was calculated in all cases using Eq. 1.2 as given in Sec. 1.2.3. Prior to calculation of efficiency it was necessary to correct all of the data for decay to a standard time following the shot. This standard time was chosen as a mean time during the actual period of counting all the layers in a pad. This resulted in a minimum correction and no extrapolation of the data for decay. The efficiency data are presented in Secs. 4.1.1 through 4.1.5 with the actual counting rate obtained at the time of counting, the decay constant from the gross decay equation

$$A = A_0 t^n,$$

where A = beta activity, c/m
A_0 = beta activity at zero time, c/m
t = time, hr
n = decay constant

and the corrected counting rate to the time used for calculation of efficiency given in the tables cited in the specific sections. The decay constant was the actual measured value for the paper in question or an extrapolated value arrived at as given in Sec. 4.4.

Counting data, as presented in the tabulated data, were corrected in all cases for coincidence, background, absorption, and geometry conditions relative to the counting system prior to tabulation.

Efficiency data are also presented in Sec. 4.1.6 for selected cases with correction of the data for decay back to H+5 hr. On the basis of these results it was considered equally accurate to report the data on the basis of the efficiency at the mean time during the actual period of counting of the test pad. In this way, the extrapolation of the data over a long period of time, where the decay constant is not accurately known, is avoided, and satisfactory accuracy is maintained on the efficiency calculations.

4.1.1 Type 5 Filter Material

The efficiency data obtained for this filter material are presented in Tables 4.1, 4.2, and 4.3 for Dog, Easy, and George Shots, respectively. The average efficiency from data taken at all altitudes from 16,000 to 30,000 ft is 88.7, 76.6, and 87.5 per cent for Dog, Easy, and George Shots, respectively. The over-all mean efficiency for the three shots was 84.1 per cent.

4.1.2 Type 6 Filter Material

The efficiency data obtained for this filter material are presented in Tables 4.4, 4.5, and 4.6 for Dog, Easy, and George Shots, respectively. The average efficiency from data taken at all altitudes from 16,000 to 30,000 ft was 99.9, 99.7, and 99.8 per cent for Dog, Easy, and George Shots, respectively. The over-all mean efficiency for the three shots was 99.8 per cent.

4.1.3 Type 7 Filter Material

The efficiency data obtained for this filter material are presented in Tables 4.7, 4.8, and 4.9 for Dog, Easy, and George Shots, respectively. The average efficiency from data taken

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at all altitudes from 16,000 to 30,000 ft was 99.7, 99.7, and 99.8 per cent for Dog, Easy and George Shots, respectively. The over-all mean efficiency for the three shots was 99.7 per cent.

4.1.4 Type 8 Filter Material

The efficiency data obtained for this filter material are presented in Tables 4.10, 4.11, and 4.12 for Dog, Easy, and George Shots, respectively. The average efficiency from data taken at all altitudes from 16,000 to 30,000 ft was 99.9, 99.6, and 99.9 per cent for Dog, Easy, and George Shots, respectively. The over-all mean efficiency for the three shots was 99.8 per cent.

4.1.5 Polyfiber Filter Material

The efficiency data obtained for this filter material are presented in Tables 4.13, 4.14, and 4.15 for Dog, Easy, and George Shots, respectively. The average efficiency from data taken at all altitudes from 16,000 to 30,000 ft was 77.3, 71.3, and 76.8 per cent for Dog, Easy, and George shots, respectively. The over-all mean efficiency for the three shots was 75.1 per cent.

4.1.6 Efficiency Based on Counting Data Corrected to H+5 hr

Decay curves were determined on selected sample pads from all three shots in which this project participated. The decay data are given in Sec. 4.4. The primary interest of this project was the determination of the efficiency of the filter materials shortly after detonation time. If the decay constant had varied with each filter paper through fractionation of the gross activity with the particles removed by each layer, a serious error in efficiency values might have resulted. To establish the validity of calculating efficiencies at the time of counting, selected calculations of efficiency were made after the counting data were corrected for decay to H+5 hr. In all cases the actual measured decay constant was used to convert the counting data. The efficiency data at H+5 hr are tabulated in Table 4.16 and compared with the efficiency data obtained on the same pad at the time of counting.

On the basis of the information shown in Table 4.16, it was considered that the validity of calculating efficiency at the time of counting was established.

TABLE 4.1 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 5, DOG SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	960,000	573.6	−1.16	958,000	1,132,959	574.4	84.6
18,000	659,000	557.5	−1.16	659,000	791,532	557.5	83.3
20,000	506,154	935.4	−1.15	506,154	569,017	935.4	89.0
22,000	754,000	480.1	−1.15	754,000	874,250	480.1	86.3
24,000	279,000	815.5	−1.15	279,000	306,097	815.8	91.2
26,000	2,530,000	507.1	−1.14	2,528,000	2,759,552	507.5	91.6
28,000	1,600,000	504.2	−1.14	1,600,000	1,756,783	504.2	91.1
30,000	329,000	725.3	−1.14	329,000	356,242	725.6	92.4

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TABLE 4.2 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 5, EASY SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	19,798	260.8	−1.37	19,880	21,357	260	93.1
18,000	1,000,000	453.7	−1.07	1,009,000	1,182,224	450	85.4
20,000	1,394,000	312.5	−1.04	1,405,700	1,677,970	310	83.8
22,000	762,000	427.5	−1.01	794,860	1,010,837	410	78.6
24,000	1,269,000	356.2	−0.99	1,291,200	1,549,903	350	83.3
26,000	700,000	307.5	−0.97	740,900	1,145,124	290	64.7
28,000	148,000	331.9	−0.95	148,810	376,756	330	39.5
30,000	833,000	293.2	−0.93	922,200	1,089,891	260	84.6

TABLE 4.3 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 5, GEORGE SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	109,280	194.4	−0.95	111,700	121,515	190	91.9
18,000	78,262	236.8	−0.99	86,510	95,249	214	90.8
20,000	238,000	335.0	−1.02	308,200	349,981	260	88.1
22,000	325,758	236.0	−1.05	327,250	370,272	235	88.4
24,000	111,000	405.8	−1.06	120,690	157,365	375	76.7
26,000	1,092,308	332.0	−1.06	1,611,400	1,790,614	230	90.0
28,000	555,556	355.2	−1.06	562,970	648,630	350	86.8
30,000	....	.....	......	....	....	...	....

TABLE 4.4 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 6, DOG SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	1,040,000	578.7	−1.16	1,036,000	1,036,648	578.7	99.9
18,000	452,000	726.4	−1.16	452,000	452,440	726.4	99.9
20,000	266,000	908.6	−1.15	266,000	266,241	908.6	99.9
22,000	362,000	889.4	−1.15	326,000	326,114	889.4	100.0
24,000	153,000	776.5	−1.15	153,000	153,734	776.8	99.5
26,000	298,000	777.3	−1.14	298,000	298,235	777.4	99.9
28,000	241,000	551.6	−1.14	241,000	241,244	551.6	99.9
30,000	205,000	726.6	−1.14	207,000	207,467	726.9	99.8

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TABLE 4.5 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 6, EASY SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	....	.....	−1.37	....	....	260	....
18,000	738,000	455.7	−1.07	748,000	749,487	450	99.8
20,000	2,030,303	331.7	−1.04	2,303,400	2,308,491	310	99.9
22,000	900,000	413.2	−1.01	928,200	929,557	410	99.8
24,000	1,369,000	360.0	−0.99	1,407,700	1,413,227	350	99.6
26,000	815,000	293.2	−0.97	823,700	825,676	290	99.8
28,000	675,000	336.3	−0.95	687,240	689,831	330	99.6
30,000	530,000	283.75	−0.93	566,800	570,507	260	99.4

TABLE 4.6 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 6, GEORGE SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	42,548	212.8	−0.95	47,387	47,535	190.0	99.7
18,000	69,878	215.2	−0.99	70,270	70,461	214.0	99.7
20,000	242,424	263.8	−1.02	246,000	246,236	260.0	99.9
22,000	276,190	239.8	−1.05	273,700	274,323	235.0	99.8
24,000	233,000	379.5	−1.06	235,970	236,073	375.0	100.0
26,000	276,923	333.5	−1.06	410,560	411,094	230.0	99.9
28,000	....	350.0	−1.06	....	....	.....	.....
30,000	....	.....	......	....	....	.....	.....

TABLE 4.7 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 7, DOG SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	222,000	571.3	−1.16	221,000	222,926	574.0	99.3
18,000	818,000	560.6	−1.16	818,000	818,445	560.6	100.0
20,000	55,280	936.9	−1.15	55,280	55,837	936.9	99.0
22,000	362,000	816.1	−1.15	362,000	362,314	816.1	99.9
24,000	267,000	814.6	−1.15	267,000	267,933	814.9	99.7
26,000	267,000	775.8	−1.14	266,000	266,235	775.8	99.9
28,000	390,000	558.1	−1.14	390,000	390,307	558.1	99.9
30,000	409,000	777.3	−1.14	409,000	409,230	777.4	99.9

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TABLE 4.8 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 7, EASY SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	....	.....	−1.37	....	....	260	....
18,000	....	.....	−1.07	....	....	450	....
20,000	606,000	334.5	−1.04	655,900	657,947	310	99.7
22,000	1,192,000	429.7	−1.01	1,250,000	1,251,857	410	99.8
24,000	1,369,000	360.8	−0.99	1,410,800	1,414,261	350	99.8
26,000	354,000	295.8	−0.97	360,860	363,161	290	99.4
28,000	802,000	336.7	−0.95	817,450	818,743	330	99.8
30,000	689,000	286.7	−0.93	743,950	746,312	260	99.7

TABLE 4.9 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 7, GEORGE SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	45,818	214.3	−0.95	51,372	51,453	190	99.8
18,000	88,191	234.2	−0.99	96,430	96,948	214	99.5
20,000	190,000	330.8	−1.02	242,900	243,085	260	99.9
22,000	280,952	239.8	−1.05	294,090	294,539	235	99.9
24,000	237,000	386.0	−1.06	244,360	244,583	375	99.9
26,000	330,769	331.3	−1.06	487,040	487,405	230	99.9
28,000	211,000	360.0	−1.06	216,860	216,969	350	100.0
30,000	....	.....	......	....	....	...	.....

TABLE 4.10 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 8, DOG SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	373,000	764.3	−1.16	373,000	373,562	764.3	99.9
18,000	532,000	720.9	−1.16	531,000	531,716	722.3	99.9
20,000	290,769	932.4	−1.15	290,769	291,668	932.4	99.7
22,000	306,000	893.5	−1.15	306,000	306,344	894.7	99.9
24,000	235,000	816.0	−1.15	235,000	235,240	816.0	99.9
26,000	183,000	549.9	−1.14	181,000	181,479	553.9	99.7
28,000	413,000	560.1	−1.14	413,000	413,354	560.1	99.9
30,000	283,000	773.8	−1.14	282,000	282,195	774.1	99.9

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Table 4.11 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 8, EASY SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	....	.....	−1.37	....	....	...	.....
18,000	....	.....	−1.07	....	....	...	.....
20,000	909,000	336.2	−1.04	989,000	989,454	310	100.0
22,000	685,000	434.2	−1.01	725,850	727,355	410	99.8
24,000	915,000	408.25	−0.99	1,065,650	1,070,616	350	99.5
26,000	825,000	312.7	−0.97	887,560	890,143	290	99.7
28,000	603,000	360	−0.95	654,970	656,480	330	99.8
30,000	270,000	264.5	−0.93	270,410	273,779	260	98.8

Table 4.12 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, TYPE 8, GEORGE SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	47,336	261.0	−0.95	64,007	64,086	190	99.9
18,000	46,131	239.3	−0.99	51,525	51,706	214	99.7
20,000	....	.....	−1.02	....	....	...	.....
22,000	295,238	239.8	−1.05	309,900	309,147	235	99.9
24,000	171,000	403.2	−1.06	184,660	185,042	375	99.8
26,000	1,000,000	234.8	−1.06	1,022,100	1,022,599	230	100.0
28,000	66,000	383.8	−1.06	72,597	72,694	350	99.9
30,000	....	.....	......	....	....	...	.....

Table 4.13 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, POLYFIBER, DOG SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	563,000	573.8	−1.16	563,000	854,913	573.8	65.2
18,000	460,000	558.2	−1.16	460,000	665,529	558.2	69.1
20,000	421,000	792.7	−1.15	421,000	513,905	792.7	81.9
22,000	452,000	480.9	−1.15	452,000	595,500	480.9	75.9
24,000	....	.....	−1.15	....	....	.....	....
26,000	338,000	343.2	−1.14	337,000	371,015	344.4	90.8
28,000	349,000	505.9	−1.14	349,000	430,967	505.9	81.0
30,000	....	.....	−1.14	....	....	.....	....

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TABLE 4.14 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, POLYFIBER, EASY SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	7,638	282.2	−1.37	8,546	9,352	260	91.4
18,000	900,000	452.8	−1.07	906,000	1,192,870	450	76.0
20,000	907,600	333.2	−1.04	978,300	1,648,810	310	59.3
22,000	746,000	431.8	−1.01	786,100	1,093,098	410	71.9
24,000	585,000	404.5	−0.99	675,100	1,192,703	350	56.6
26,000	900,000	331	−0.97	1,026,000	1,570,375	290	65.3
28,000	1,000,000	359	−0.95	1,083,200	1,287,732	330	84.1
30,000	1,030,000	308	−0.93	1,196,000	1,822,250	260	65.6

TABLE 4.15 FILTER MATERIAL EFFICIENCIES AGAINST GROSS BOMB CONTAMINANT, POLYFIBER, GEORGE SHOT, FIRST LAYER

ALTITUDE (ft)	MEASURED COUNTING RATE (c/m)	TIME OF COUNTING AFTER SHOT (hr)	DECAY CONSTANT FOR CORRECTION OF DATA	CORRECTED COUNTING RATE (c/m)	CORRECTED TOTAL COUNTING RATE OF PAD (c/m)	TIME OF CALCULATION OF EFFICIENCY AFTER SHOT (hr)	EFFICIENCY (per cent)
16,000	39,180	215.2	−0.95	44,100	60,852	190	72.5
18,000	51,563	237.0	−0.99	57,044	73,533	214	77.6
20,000	190,000	356.3	−1.02	262,000	360,052	260	72.8
22,000	377,778	236.0	−1.05	379,500	469,650	235	80.8
24,000	....	.....	−1.06	....	....	...	....
26,000	292,308	356.3	−1.06	464,840	583,094	230	79.7
28,000	109,000	383.9	−1.06	119,990	154,602	350	77.6
30,000	....	.....	......	....	....	...	....

TABLE 4.16 COMPARISON OF EFFICIENCY DATA CALCULATED FROM COUNTING DATA TAKEN AT A MEAN TIME DURING THE PERIOD OF COUNTING AND COUNTING DATA CORRECTED FOR DECAY TO H+5 HR

SAMPLE NO.	EFFICIENCY AT MEAN COUNTING TIME (per cent)	EFFICIENCY AT H+5 HR (per cent)	SAMPLE NO.	EFFICIENCY AT MEAN COUNTING TIME (per cent)	EFFICIENCY AT H+5 HR (per cent)
DB61	99.9	99.9	EA54	76.7	76.7
DB71	99.9	99.9	EAAF1	65.6	65.7
DB81	99.7	99.7	EAAF2	64.2	64.3
DB51	91.6	91.9	EAAF3	53.4	53.8
DB52	82.0	82.7	EAAF4	64.2	63.7
DB53	68.0	68.4	GK61	99.7	99.7
DB54	60.7	61.1	GK71	99.5	99.5
DBPF1	90.8	90.5	GK81	99.6	99.6
DBPF2	66.8	66.7	GIAF1	80.8	80.8
DBPF3	64.9	64.8	GIAF2	44.0	43.9
DBPF4	71.5	71.4	GIAF3	60.9	60.9
EA61	99.4	99.4	GIAF4	67.0	67.0
EA71	99.7	99.7	GI51	88.4	88.8
EA81	98.8	98.8	GI52	77.1	77.1
EA51	84.6	84.6	GI53	62.4	62.4
EA52	76.3	76.3	GI54	70.7	70.7
EA53	73.6	73.6			

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4.2 VARIATION IN FILTER EFFICIENCY WITH LAYERS

In the case of relatively low-efficiency filter materials, such as Type 5 and polyfiber filter material, it is possible to calculate the efficiency of the second, third, and fourth layers in a pad with satisfactory accuracy. These filter materials are of the low air resistance, and low-efficiency per layer type. When used for filtration purposes, they are made into multilayer units to achieve high filtration efficiency. In the case of the high-efficiency filter materials, such as Types 6, 7, and 8, this type of calculation cannot be made with any satisfactory degree of accuracy unless the test conditions and handling are laboratory controlled. It is not possible to expect to achieve the required conditions in a field test of this type.

The efficiency of the secondary layers was calculated in the same manner as the first layers using Eq. 1.2 in Sec. 1.2.3, modified to eliminate consideration of all preceding influent layers of filter material.

4.2.1 Type 5 Filter Material

The data on Type 5 filter material are shown in Tables 4.17, 4.18, and 4.19 for Dog, Easy, and George Shots, respectively. The mean efficiency of Type 5 filter material on Dog Shot was 88.7, 77.0, 68.6, and 63.6 per cent for the first through fourth layers, respectively. On Easy Shot the mean efficiency was 74.3, 70.0, 63.0, and 51.8 per cent for the first through fourth layers, respectively. On George Shot, the mean efficiency was 87.5, 75.7, 65.4, and 56.9 per cent for the first through fourth layers, respectively.

TABLE 4.17 VARIATION IN FILTER EFFICIENCY WITH TYPE 5 LAYERS, DOG SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
16,000	84.6	76.6	74.2	76.6	H+574.4
18,000	83.3	74.1	65.4	62.8	H+557.5
20,000	89.0	76.4	67.4	56.4	H+935.4
22,000	86.3	74.6	64.5	43.0	H+480.1
24,000	91.2	72.9	58.8	58.6	H+815.8
26,000	91.6	82.0	68.0	60.7	H+507.5
28,000	91.1	77.7	73.2	76.5	H+504.2
30,000	92.4	81.6	77.3	74.3	H+725.6

TABLE 4.18 VARIATION IN FILTER EFFICIENCY WITH TYPE 5 LAYERS, EASY SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
18,000	85.4	68.9	52.8	30.1	H+450.0
20,000	83.8	67.6	63.5	42.6	H+310.0
22,000	78.6	74.6	67.0	65.5	H+410.0
24,000	83.3	73.5	62.6	50.2	H+350.0
26,000	64.7	61.6	54.1	37.4	H+290.0
28,000	39.5	67.4	67.3	59.8	H+330.0
30,000	84.6	76.3	73.6	76.7	H+264.0

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TABLE 4.19 VARIATION IN FILTER EFFICIENCY WITH TYPE 5 LAYERS, GEORGE SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
16,000	91.9	78.1	64.8	54.2	H+190.0
18,000	90.8	74.5	53.5	43.4	H+214.0
20,000	88.1	74.2	69.6	54.2	H+260.0
22,000	88.4	77.1	62.4	70.7	H+235.0
24,000	76.7	75.6	65.2	53.0	H+375.0
26,000	90.0	74.0	68.1	60.6	H+230.0
28,000	86.8	76.2	73.9	62.2	H+350.0

TABLE 4.20 VARIATION IN FILTER EFFICIENCY WITH POLYFIBER LAYERS, DOG SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
16,000	65.2	49.2	63.6	70.1	H+573.8
18,000	69.1	78.8	77.5	80.0	H+558.2
20,000	81.9	40.0	61.1	63.3	H+792.7
22,000	75.9	68.0	65.3	23.8	H+480.9
26,000	90.8	66.8	64.9	71.5	H+344.4
28,000	81.0	64.2	58.6	72.4	H+505.9

4.2.2 Polyfiber Filter Material

The data on the polyfiber filter material are shown in Tables 4.20, 4.21, and 4.22 for Dog, Easy, and George Shots, respectively. The median efficiency of the polyfiber filter material on Dog Shot was 77.3, 61.3, 65.2, and 63.5 per cent on the first through fourth layers, respectively. On Easy Shot the mean efficiency was 68.4, 59.1, 50.5, and 59.9 per cent on the first through fourth layers, respectively. On George Shot the mean efficiency was 76.8, 56.7, 57.8, and 64.3 per cent on the first through fourth layers, respectively.

4.3 PER CENT PENETRATION OF FILTER MATERIAL AND COMPARISON WITH STANDARD TEST AEROSOL DATA

The data can also be presented in graphical form by calculating the per cent penetration of the first layer, first and second layers, first, second, and third layers, and the first through fourth layers by the use of Eq. 1.3 as outlined in Sec. 1.2.3. The per cent penetration data can then be presented graphically in the manner shown in Fig. 1.1. This was done for the Type 5 and the polyfiber filter material on all shots. These data are shown on Figs. 4.1, 4.2, and 4.3 for the Type 5 filter material on Dog, Easy, and George Shots, respectively. The data are shown on Figs. 4.4, 4.5, and 4.6 for the polyfiber filter material on these same shots, respectively. The mean curve for the data is shown for all altitudes sampled. Also shown for comparison on Figs. 4.1 to 4.6 is the average methylene blue and dioctylphthalate penetration data taken on filter material from representative locations on the same rolls of filter material from which the test pads were prepared.

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TABLE 4.21 VARIATION IN FILTER EFFICIENCY WITH POLYFIBER LAYERS, EASY SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
18,000	76.0	64.0	65.4	70.8	H+450.0
20,000	59.3	54.3	57.8	59.8	H+310.0
22,000	71.9	64.6	66.1	71.1	H+410.0
24,000	56.6	52.3	59.2	63.3	H+350.0
26,000	65.3	38.7	30.2	15.4	H+290.0
28,000	84.1	75.4	21.4	74.5	H+330.0
30,000	65.6	64.2	53.4	64.2	H+264.0

TABLE 4.22 VARIATION IN FILTER EFFICIENCY WITH POLYFIBER LAYERS, GEORGE SHOT

ALTITUDE (ft)	LAYER 1 (per cent)	LAYER 2 (per cent)	LAYER 3 (per cent)	LAYER 4 (per cent)	TIME (hr)
16,000	72.5	61.0	50.0	70.9	H+190.0
18,000	77.6	55.8	54.9	75.7	H+214.0
20,000	72.8	62.9	63.1	56.3	H+260.0
22,000	80.8	44.0	60.8	67.0	H+235.0
24,000	....	57.4	56.0	67.2	H+375.0
26,000	79.7	56.3	59.1	60.7	H+230.0
28,000	77.6	59.5	60.5	52.4	H+350.0

4.4 RADIOAUTOGRAPH DATA

The radioautographs taken on the influent and effluent sides of the filter papers showed no significant difference in the type of result obtained. Thus it was determined that single radioautographs taken on the influent side of the filter paper would be satisfactory for analysis.

Figure 4.7 shows one set of radioautographs taken from a test pad of Type 5 filter material. This sample was collected by Baker drone at an altitude of 26,000 ft on Easy Shot. It illustrates all the types of radioautographs obtained with evidence of degrees of edge and rim leakage.

In Table 4.23 are tabulated the data on the results of all radioautographs, based on an estimate of the degree of leakage and its effect on the efficiency results. The general observation can be made that leakage was markedly less on the George Shot samples. This was minimized through sealing the edges of the pads with Scotch tape after mounting on the sampling apparatus.

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TABLE 4.23 LEAKAGE OF FILTER PADS

TYPE OF PAPER		POLYFIBER					5					6			7			8		
Layer	Number	1	2	3	4	5	1	2	3	4	5	1	2	3	1	2	3	1	2	3
Shot	*Drone*																			
Dog	Able	A	A	A	A	B	A	A	B	B	B	A	B	B	A	B	B	A	B	B
Dog	Baker	A	A	A	A	A	A	B	B	B	C	A	B	B	A	B	B	A	B	B
Dog	Charlie	X	X	X	X	X	X	X	X	X	X	X	A	A	X	A	A	X	B	B
Dog	Dog	A	A	A	A	A	A	B	B	B	C	X	A	B	A	B	B	A	B	B
Dog	Easy	A	A	A	A	A	A	B	B	B	B	A	A	B	A	B	B	A	B	B
Dog	Jig	A	B	B	B	B	A	B	B	B	C	A	B	B	A	B	B	A	B	C
Dog	King	A	A	A	A	A	A	B	B	B	C	A	B	B	A	B	B	A	B	B
Dog	Love	X	X	X	X	X	X	X	X	X	X	X	B	B	X	B	B	X	B	C
Easy	Able	X	X	X	X	X	X	X	X	X	X	X	B	C	X	B	B	X	B	C
Easy	Baker	A	A	A	A	B	A	B	B	B	C	A	B	B	A	B	B	A	B	B
Easy	Charlie	A	B	B	A	X	A	B	B	B	C	A	B	B	A	B	B	A	B	B
Easy	Dog	A	X	A	B	B	A	B	B	B	C	A	B	B	A	B	C	A	B	B
Easy	Item	A	B	A	A	A	A	B	B	B	C	A	B	B	A	A	B	A	B	B
Easy	Jig	X	X	X	X	X	X	X	X	X	X	X	B	B	X	B	B	X	B	C
Easy	King	A	B	B	B	B	A	B	B	B	C	A	B	B	A	B	B	A	B	B
Easy	Love	X	X	X	X	X	X	X	X	X	X	X	A	A	X	A	A	X	A	A
George	Baker	X	X	X	X	X	X	X	X	X	X	X	B	B	X	A	B	X	A	A
George	Charlie	A	A	A	A	A	A	A	B	B	B	A	A	A	A	A	A	A	A	A
George	Dog	A	A	A	A	A	A	A	A	A	B	A	A	B	A	B	B	A	B	B
George	Item	X	X	X	X	X	X	X	X	X	X	X	A	A	X	A	A	X	A	A
George	Jig	A	A	A	A	B	A	A	A	A	B	A	A	B	A	A	A	A	B	B
George	King	A	A	A	A	A	A	A	A	A	B	A	A	A	A	A	A	A	A	A
George	Love	X	X	X	X	X	X	X	X	X	X	X	A	A	X	A	A	X	A	A

A indicates no leak; B, leak which should not affect efficiency; C, leak which should affect efficiency; X, paper was not radioautographed.

4.5 GROSS DECAY DATA

Gross beta decay was taken on selected samples from each test in which this project participated. Decay data were taken at two altitudes, 28,000 and 16,000 ft, on Dog Shot; three altitudes, 30,000, 20,000, and 16,000 ft, on Easy Shot; and three altitudes, 26,000, 22,000, and 16,000 ft, on George Shot. The first layers of Types 6, 7, and 8 filter material, and the first through fifth layers of Type 5 and the polyfiber filter material, were measured.

Decay data were taken over the period of approximately H+250 hr to H+2,000 hr. Generally, the decay data followed the general form of the equation $A = A_0 t^n$. Each determination was made for a total count of at least 10,000 counts above background to obtain a 2 per cent fractional error. The decay data are tabulated in Table 4.24 for the first layers of Types 6, 7, and 8 filter material on all shots, and in Table 4.25 for Type 5 and the polyfiber filter material. The variation in the results is discussed in detail in Sec. 5.2, "Significance of Decay Data." The mean decay slope was found to be -1.08 ± 0.03 for all the data taken.

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TABLE 4.24 BETA ACTIVITY DECAY DATA, TYPES 6, 7, AND 8 FILTER MATERIAL

DOG SHOT				EASY SHOT				GEORGE SHOT			
Sample No.	Decay Constant (−n)	Time of Measurement after Shot		Sample No.	Decay Constant (−n)	Time of Measurement after Shot		Sample No.	Decay Constant (−n)	Time of Measurement after Shot	
		Begin (hr)	End (hr)			Begin (hr)	End (hr)			Begin (hr)	End (hr)
DC61	0.94	552	1,555	EA61	1.05	284	1,818	GB61	0.97	332	1,506
DL61	1.05	580	1,555	EJ61	0.63	331	1,988	GL61	0.78	212	1,412
DC71	1.30	558	1,735	EL61	1.32	261	1,843	GI61	1.28	232	1,512
DL71	1.09	750	1,590	EA71	0.63	263	1,818	GB71	1.27	330	1,506
DC81	1.38	560	1,555	EJ71	1.19	335	1,969	GL71	1.06	212	1,412
DL81	1.09	770	1,560	EL71	1.72	288	1,843	GI71	1.12	239	1,512
				EA81	0.64	264	1,819	GB81	1.24	234	1,506
				EJ81	0.96	460	1,968	GL81	1.14	260	1,412
				EL81	1.51	290	1,843	GI81	1.10	238	1,512

TABLE 4.25 BETA ACTIVITY DECAY DATA, TYPE 5 AND POLYFIBER FILTER MATERIAL

DOG SHOT				EASY SHOT				GEORGE SHOT			
Sample No.	Decay Constant (−n)	Time of Measurement after Shot		Sample No.	Decay Constant (−n)	Time of Measurement after Shot		Sample No.	Decay Constant (−n)	Time of Measurement after Shot	
		Begin (hr)	End (hr)			Begin (hr)	End (hr)			Begin (hr)	End (hr)
DC51	1.38	505	1,550	EA51	0.67	270	1,820	GB51	1.09	331	1,504
DC52	1.14	435	1,560	EA52	0.94	271	1,820	GB52	0.98	332	1,504
DC53	1.05	365	1,560	EA53	1.05	271	1,820	GB53	0.97	332	1,504
DC54	1.00	265	1,410	EA54	1.14	271	1,820	GB54	0.96	332	1,503
DC55	1.21	295	1,430	EA55	1.15	272	1,819	GB55	1.15	332	1,503
DL51	1.29	575	1,560	EJ51	0.68	314	1,988	GL51	1.14	194	1,414
DL52	1.33	575	1,560	EJ52	1.02	314	1,988	GL52	0.87	194	1,414
DL53	1.16	360	1,655	EJ53	1.12	314	1,988	GL53	0.85	193	1,414
DL54	1.14	365	1,440	EJ54	1.10	314	1,988	GL54	0.71	192	1,174
DL55	1.16	365	1,440	EJ55	1.36	315	1,824	GL55	1.12	192	1,025
DCPF1	0.92	506	1,555	EL51	1.30	260	1,846	GI51	1.13	235	1,511
DCPF2	1.16	366	1,555	EL52	1.30	263	985	GI52	0.97	234	1,511
DCPF3	1.12	366	2,053	EL53	2.64	265	985	GI53	0.92	234	1,512
DCPF4	1.13	355	1,410	EL54	1.81	266	985	GI54	1.12	234	1,535
DCPF5	1.09	300	1,250	EL55	1.43	266	983	GI55	0.93	234	1,535
DLPF1	1.22	563	1,555	EAPF1	0.73	282	1,823	GBPF1	1.17	356	1,170
DLPF2	1.13	571	1,555	EAPF2	1.06	283	1,822	GBPF2	0.98	356	1,506
DLPF3	1.17	435	1,555	EAPF3	1.02	284	1,821	GBPF3	0.94	356	1,506
DLPF4	1.13	335	1,440	EAPF4	1.00	285	1,821	GBPF4	1.04	356	1,508
DLPF5	1.10	365	1,440	EAPF5	1.02	285	1,820	GBPF5	1.03	358	1,508
				EJPF1	0.78	357	1,970	GLPF1	1.09	214	1,413
				EJPF2	1.08	359	1,970	GLPF2	0.92	214	1,413
				EJPF3	1.20	360	1,970	GLPF3	0.91	214	1,414
				EJPF4	1.17	360	1,988	GLPF4	0.92	214	1,414
				EJPF5	1.19	360	1,988	GLPF5	0.89	214	1,414
				ELPF1	1.20	259	1,847	GIPF1	1.19	235	1,510
				ELPF2	0.93	260	1,005	GIPF2	0.99	234	1,510
				ELPF3	0.45	260	1,005	GIPF3	0.99	234	1,511
				ELPF4	1.17	261	1,004	GIPF4	1.00	234	1,511
				ELPF5	1.02	261	1,843	GIPF5	0.97	234	1,511

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4.6 ALPHA ACTIVITY DATA

As outlined in Sec. 3.7.2, a 1½-in. disk of filter paper was cut out of the center of a 100-sq cm layer of filter material for counting alpha activity. The alpha activity measurements were confined to selected samples of the first layer of a test pad only.

On Dog Shot samples, the first layers of all types of filter material from the 30,000-, 28,000-, 26,000-, 24,000-, 20,000-, and 16,000-ft aircraft were counted. The alpha activity measured ranged from 0.019 to 2.05 c/m above background. The average time of measurement was D+100 days.

On Easy Shot only the first layers of each type from the 24,000-ft aircraft were counted. The alpha activity ranged from 2.04 to 3.21 c/m above background.

On George Shot negligible alpha activity was measured on four random samples from the 26,000-, 20,000-, and 18,000-ft aircraft, representing Types 5, 6, and 8 filter material. The highest alpha activity measured was 0.9 c/m above background, with two values at 0.1 c/m and one value at no detectable alpha activity.

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Chapter 5

Discussion

5.1 SIGNIFICANCE OF FILTER EFFICIENCY RESULTS

The data given in Secs. 4.1.1 through 4.1.5 are particularly significant as to the effectiveness of the filter materials in the filtration of gross bomb contaminant, indicating that there is no significant change in the filtration efficiency over the measurements made with laboratory-controlled aerosols used for test purposes. The sensitivity of the measurements was not sufficient to verify the increased efficiency (referred to in Sec. 1.1) noted in laboratory experiments with highly radioactive laboratory test aerosols. The data did indicate, however, that the presence of the high levels of radioactivity associated with the particulate matter in the cloud have no deleterious effect on the filtration properties of the respiratory filter materials evaluated.

It is considered that the correlation of the filtration efficiency data with the methylene blue and dioctylphthalate data shown in Figs. 4.1 to 4.6 can be used to obtain an indication of the gross particle-size distribution in the cloud. The methylene blue test aerosol has an average diameter of approximately 0.8 μ and the dioctylphthalate test aerosol has an average diameter of approximately 0.3 μ. These particular test aerosols were developed in the particle size stated based upon theoretical and experimental work which has shown this size range to be the most penetrating for the filter materials of interest for respiratory use. The filter materials evaluated have an efficiency that varies markedly with particle size, increasing noticeably for the removal of particles larger than the size of the laboratory test aerosols. Since the efficiency data obtained in this test work closely approximate the data obtained with the laboratory test aerosols, they indicate that the particle-size distribution of the radioactive component of the gross particulate cloud contaminant is in the size range of 0.3 to 1.0 μ in diameter.

5.2 SIGNIFICANCE OF DECAY DATA

The data in Sec. 4.5 give the beta decay for selected filter samples from all shots. Since the validity of any decay slope is dependent upon the accuracy of counting, each count was made for at least a total count of 10,000 counts above background, which means any count is within 2 per cent of the true count 95 per cent of the time. The extremely low sample-to-background ratio made it inadvisable to use any information obtainable from the two effluent layers of the Types 6, 7, and 8 filter material. In all cases the sample counting rate for these papers was less than twice that of background.

The decay constant was determined from the counting data by determining the decay slope through the least-squares method. The maximum deviation of any point on a decay curve from the true value was 17 per cent while the absolute mean deviation was 4 per cent. This is a good indication of the accuracy of the determination of the decay data for the sample in question.

To analyze further the data obtained, since the decay constant ranged from a low of -0.45 to a high of -2.64 for the data from all three shots, a three-way test of variance was applied to determine the significance of the variations between the decay constant and the relationship of this variation to the shot, the altitude of sampling, the types of filter material used,

[redacted]

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and the position of any sample in a test pad. This test of variance indicated no relationship between the variation in decay constant and the type of filter material used or the position of a sample in a test pad. However, statistical analysis of the data did show a definite relationship between the variation in the decay constant and altitude. It was shown that more than 99 per cent of the time the decay constants for a given shot would vary with change in altitude; nevertheless, no definite trend of consistency in this variation of decay constants was shown for all three shots.

The mean decay constant was found to be -1.08 ± 0.03 for all decay constants determined by counting methods. The individual points used to determine the decay constants were counted with a 95 per cent probability and 2 per cent fractional error.

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Chapter 6

Conclusions

6.1 FILTRATION EFFICIENCY

6.1.1 Efficiency of Types 6, 7, and 8 Filter Material

It is concluded that the mean efficiency of Chemical Corps respiratory protective filter material Types 6, 7, and 8 is at least 99.8, 99.7, and 99.8 per cent, respectively, against the gross particulate contaminant existing in an atomic bomb cloud 3 to 14 min after detonation, within the limits of sensitivity of the experimental methods and procedures.

6.1.2 Efficiency of Type 5 Filter Material

It is concluded that the mean efficiency of Chemical Corps respiratory protective filter material Type 5 is 84.1 per cent against the gross particulate contaminant existing in an atomic bomb cloud 3 to 14 min after detonation.

6.1.3 Efficiency of Polyfiber Filter Material

It is concluded that the mean filtration efficiency of the polyfiber filter material developed for the U. S. Air Force for air sampling is 74.3 per cent at a flow rate of 320 cm/min against the gross bomb particulate contaminant.

6.1.4 Efficiency Against High Levels of Radioactivity

It is concluded that no deleterious effect on filter efficiency results during the filtration of high levels of gross fission product beta and gamma activity such as are present in an atomic bomb cloud 3 to 14 min after detonation.

6.1.5 Selective Filtration of the Particulate Matter

Based on efficiency measurements, there is an indication of the selective filtration of the cloud particulate matter by successive layers in a test pad of Type 5 and polyfiber filter material. The increased penetration of the successive effluent layers is due to the higher efficiency of the filter material for the removal of large particles, the greatest fraction of which are removed on the first influent layer.

6.2 SAMPLING SYSTEM

It is concluded that the sampling system was as nearly isokinetic as feasible to attain in a field experiment and that the studies reported herein were conducted against a representative sample of the atomic bomb cloud.

6.3 DECAY DATA

6.3.1 Gross Beta Decay Constant

The data on decay of the filter samples indicate that the average decay constant, n, in the equation $A = A_0 t^n$ is approximately -1.08 during the period H+250 to H+2,000 hr.

6.3.2 Variations in the Decay Constant

The data on decay indicate that the decay constant, n, varies with altitude and shot. No consistent variation can be obtained with relation to type of shot, altitude, or test conditions.

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6.3.3 Selective Filtration of Gross Contaminant

Decay data indicate that there is no selective filtration of gross fission-product contaminant with relation to types of filter material, or layer in a test pad.

6.4 PARTICLE SIZE OF THE RADIOACTIVE COMPONENT OF THE CLOUD

On the basis of the correlation of the actual efficiency data obtained on all types of filter materials evaluated with the standard laboratory test aerosol efficiency data, it is indicated that the median size of the active particulate matter is in the range 0.3 to 1.0 μ in diameter.

6.5 HOMOGENEITY OF THE PARTICLE-SIZE DISTRIBUTION IN THE CLOUD

On the basis of the variation in filtration efficiency with successive layers in a test pad, as stated in Sec. 6.1.5, the cloud-particle-size distribution is considered to be extremely heterogeneous.

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Appendix A

Roster of Personnel and Shipping Information

I ROSTER OF PERSONNEL

NOTE: All personnel who worked on this project are from the Radiological Division, Chemical and Radiological Laboratories, Army Chemical Center, Maryland. Personnel who participated in the overseas phase of the project are indicated by an asterisk.

NAME	DUTIES
*Elmer H. Engquist Chemical and Electronic Engineer	Project Officer. Carried out pre-test planning, designed sampling apparatus, supervised calibration of equipment, flight tests, on-site operations, compilation and analysis of data. Prepared final report on the project.
*John R. Hendrickson Physical Chemist	Assistant Project Officer. Supervised pre-test laboratory work, including calibration of equipment and testing of units following manufacture. Assisted in first two shots on-site operations.
*Edward F. Wilsey Physical Chemist	Assembled and tested filter materials, and tested units following manufacture, including calibration, in pre-test work. Set up counting equipment and conducted on-site analysis. Conducted radioautographic analyses in post-test work at Army Chemical Center. Assisted in preparation of final report.
*Robert C. Tompkins Analytical Chemist	Analyzed pre-test data, prepared sections of pre-test and final report, planned analysis of samples, supervised on-site and Army Chemical Center analysis of samples after return from overseas.
Philip W. Krey Physical Chemist	Pre-test calibration and testing of units. In charge of counting-room operations, including calculation of data.
D'Arcy A. Littleton, Jr. Engineering Aide (Electronics)	Assisted in analysis of samples, calculation of data, and compilation of results. Carried out preliminary work for radio-autograph studies.
Phyllis W. Beamer Chemist	In charge of analysis of samples at Army Chemical Center. Compiled all data, tabulated results, applied corrections for coincidence and decay, graphical representation of data, and tests for significance of results. Prepared draft sections of report relating to analysis of samples, results, and discussions.
Dean Miller Chemical Engineer	Assisted Miss Beamer in the above work.

II SHIPPING

	AIR LIFT		SEA LIFT	
	Pounds	*Cubic Feet*	*Pounds*	*Cubic Feet*
To Forward Area	2,591	173	2,805	26
Return	1,021	42	3,210	141

[redacted]

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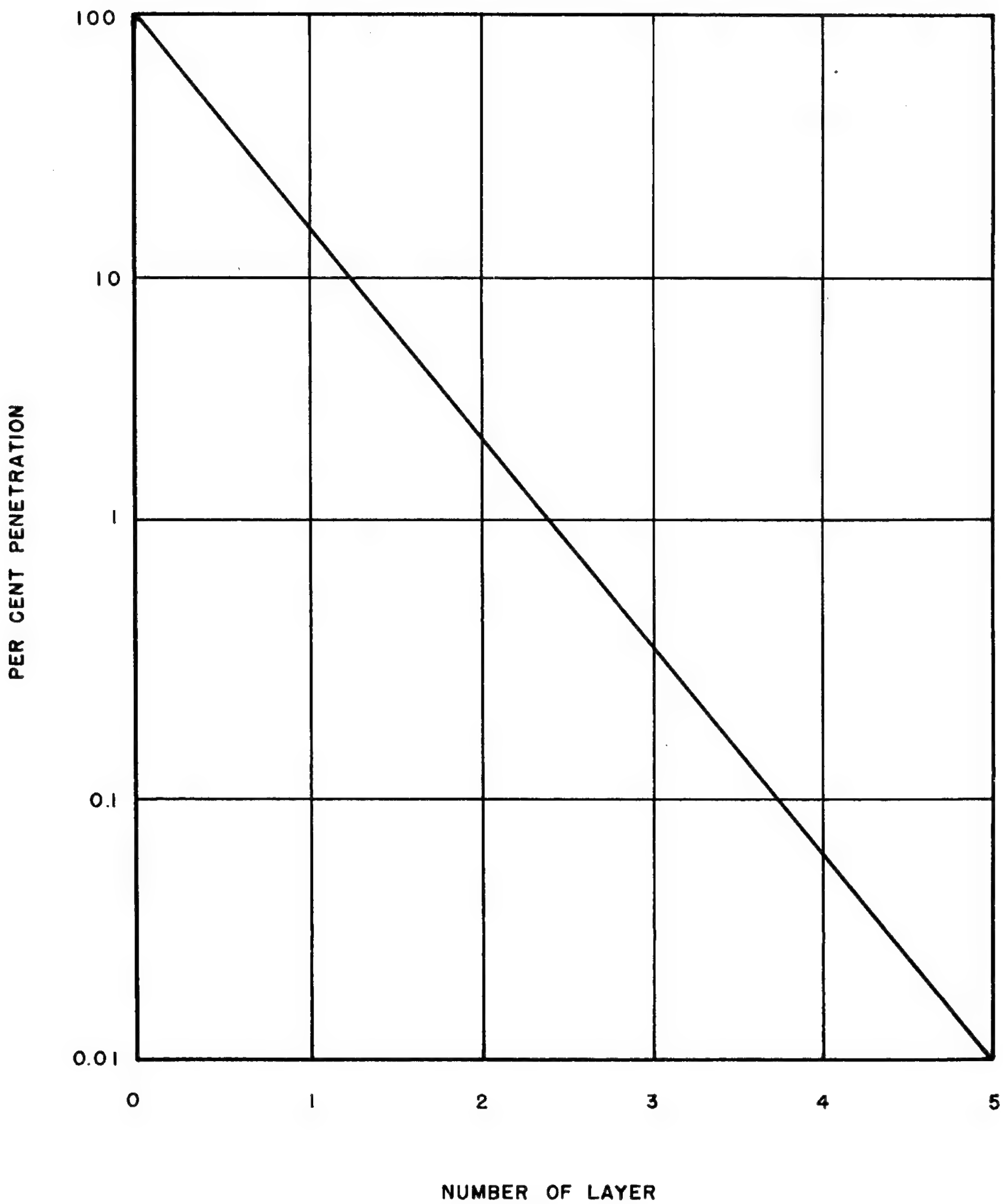

Fig. 1.1 Representation of Penetration Data

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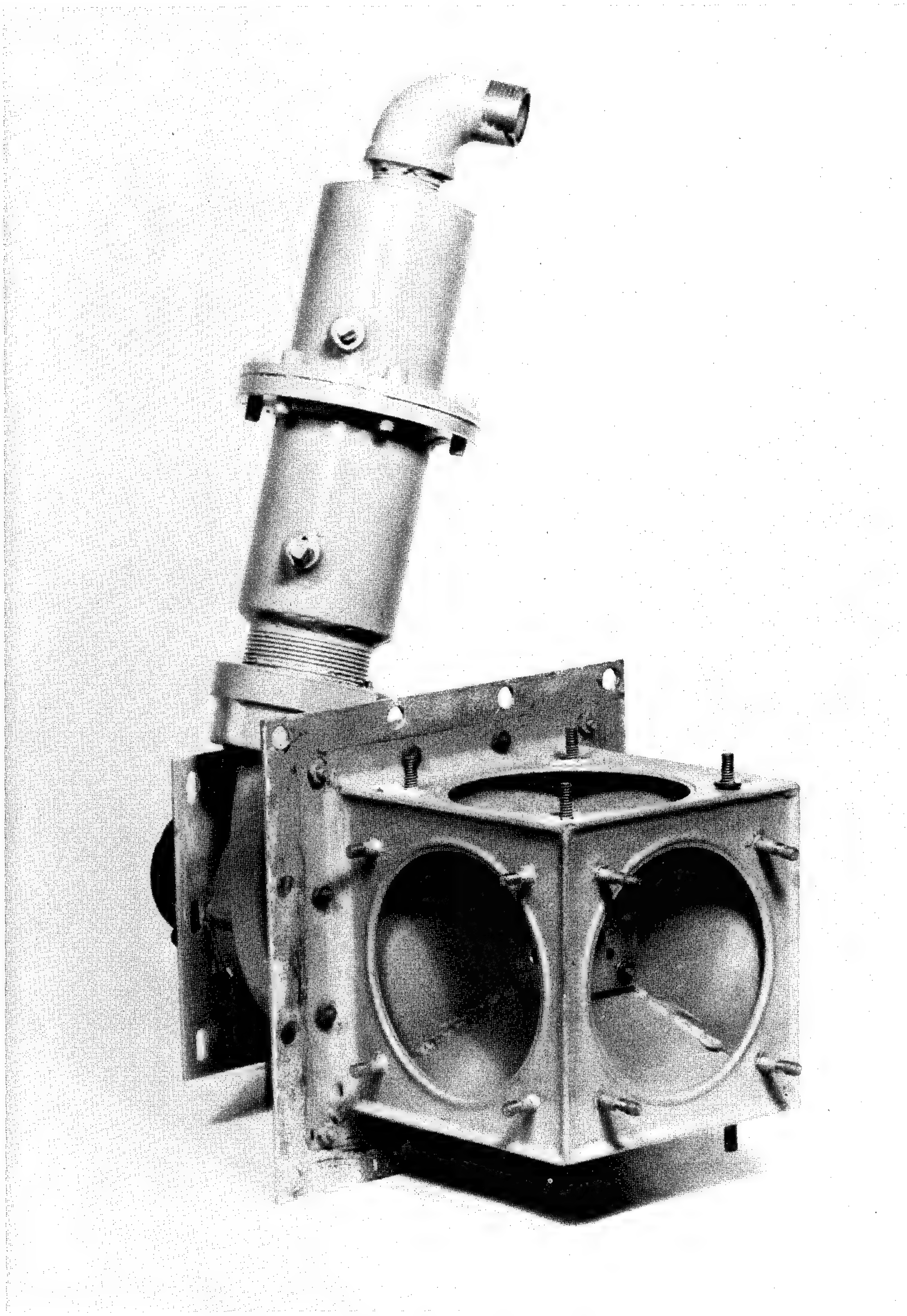

FIG. 2.1 Filter Material Sampler (Unassembled)

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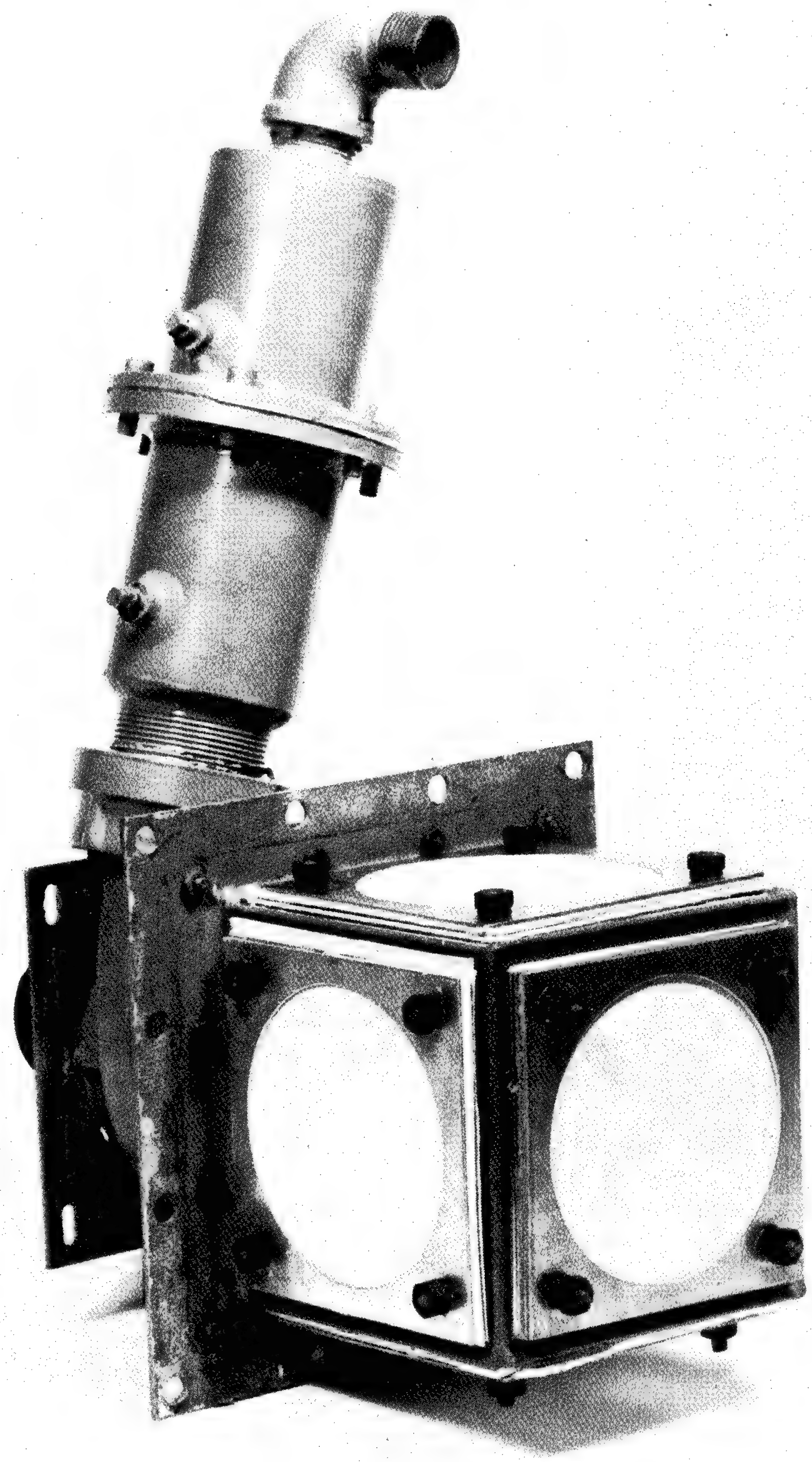

FIG. 2.2 Filter Material Sampler (Assembled with Filter Material)

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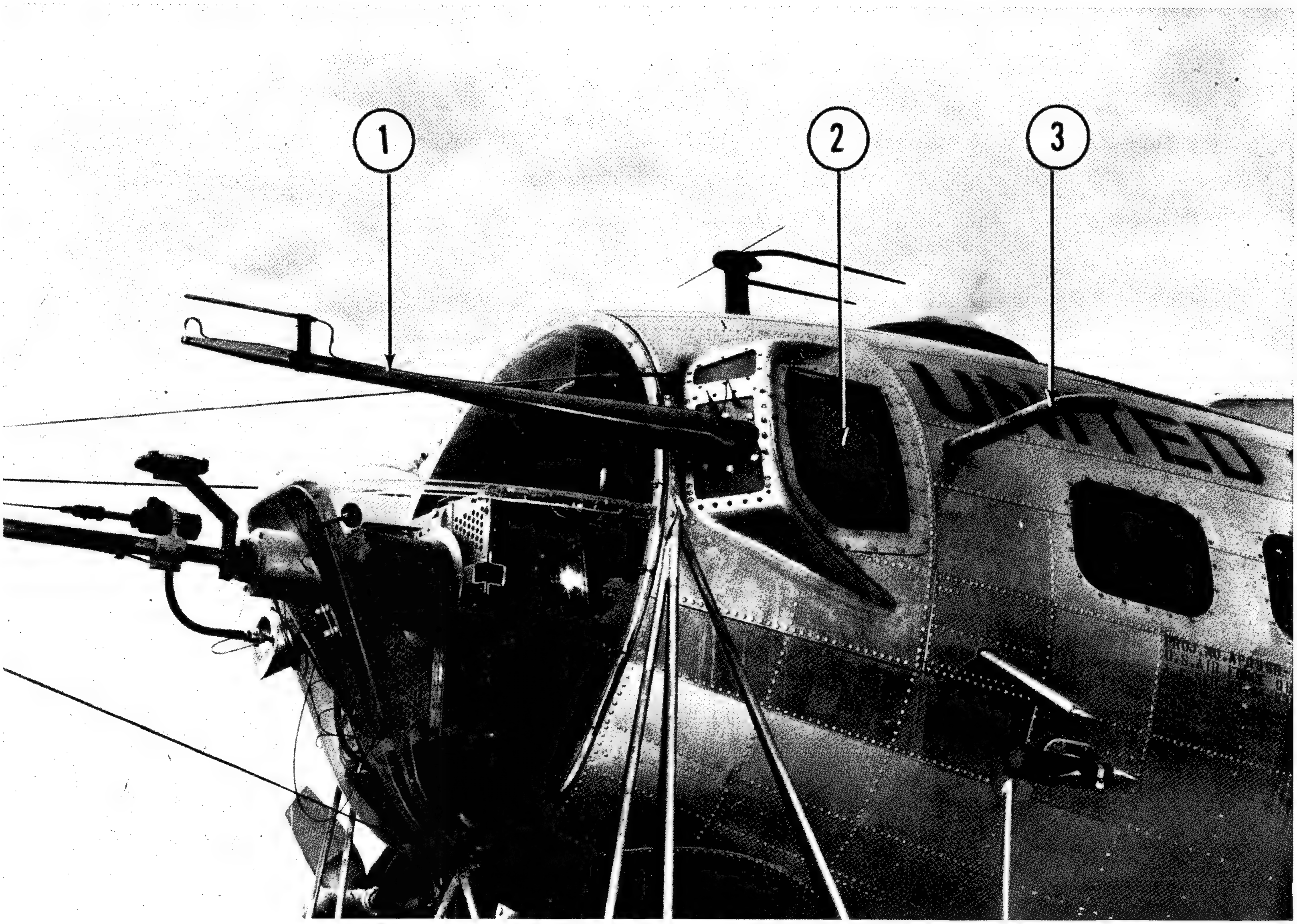

FIG. 2.3 Chemical Corps Sampling Probe Installation: (1) Probe; (2) Plenum Chamber; (3) Exhaust Tube

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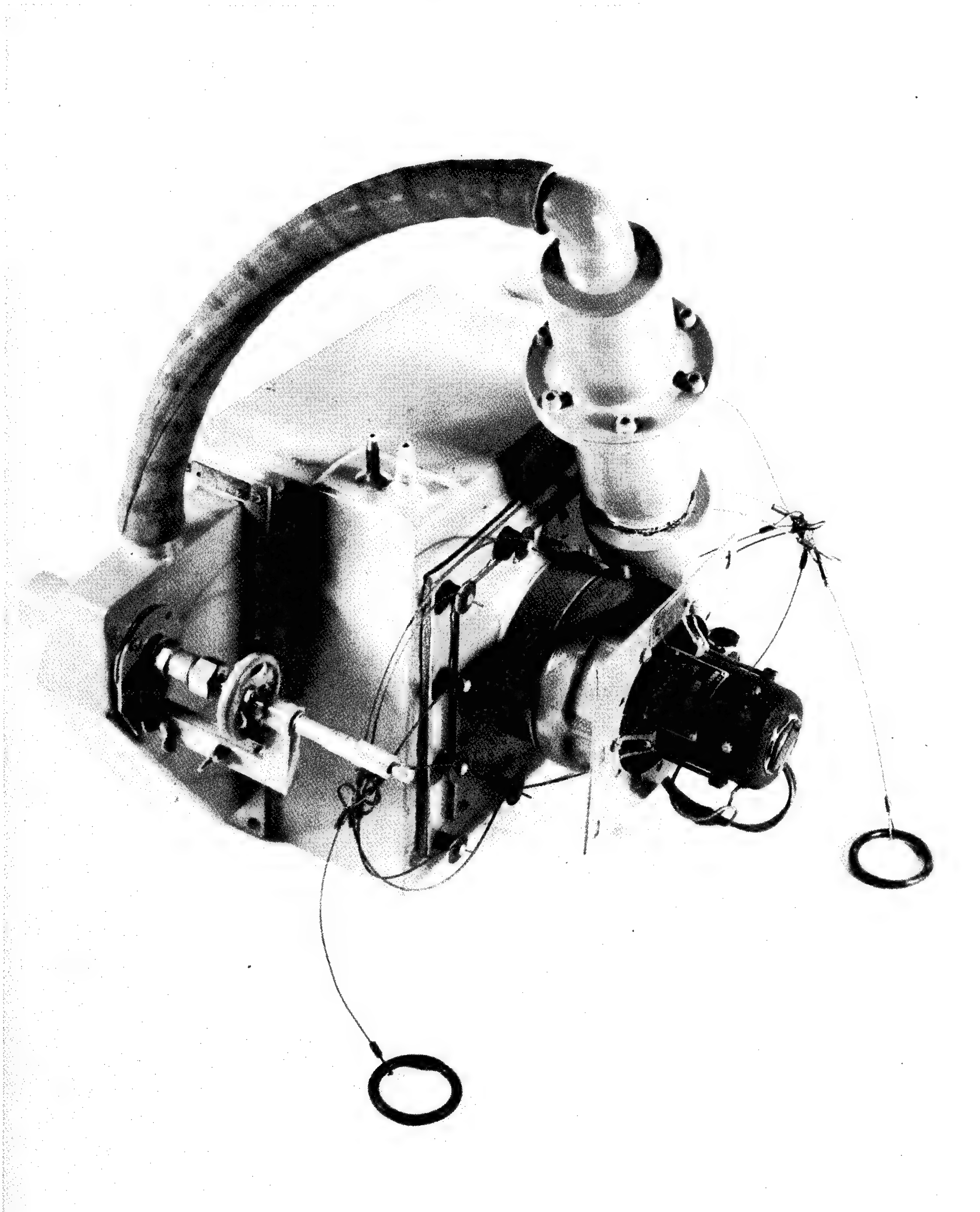

FIG. 2.4 Filter Material Sampler, Plenum Chamber, and Exhaust Valve

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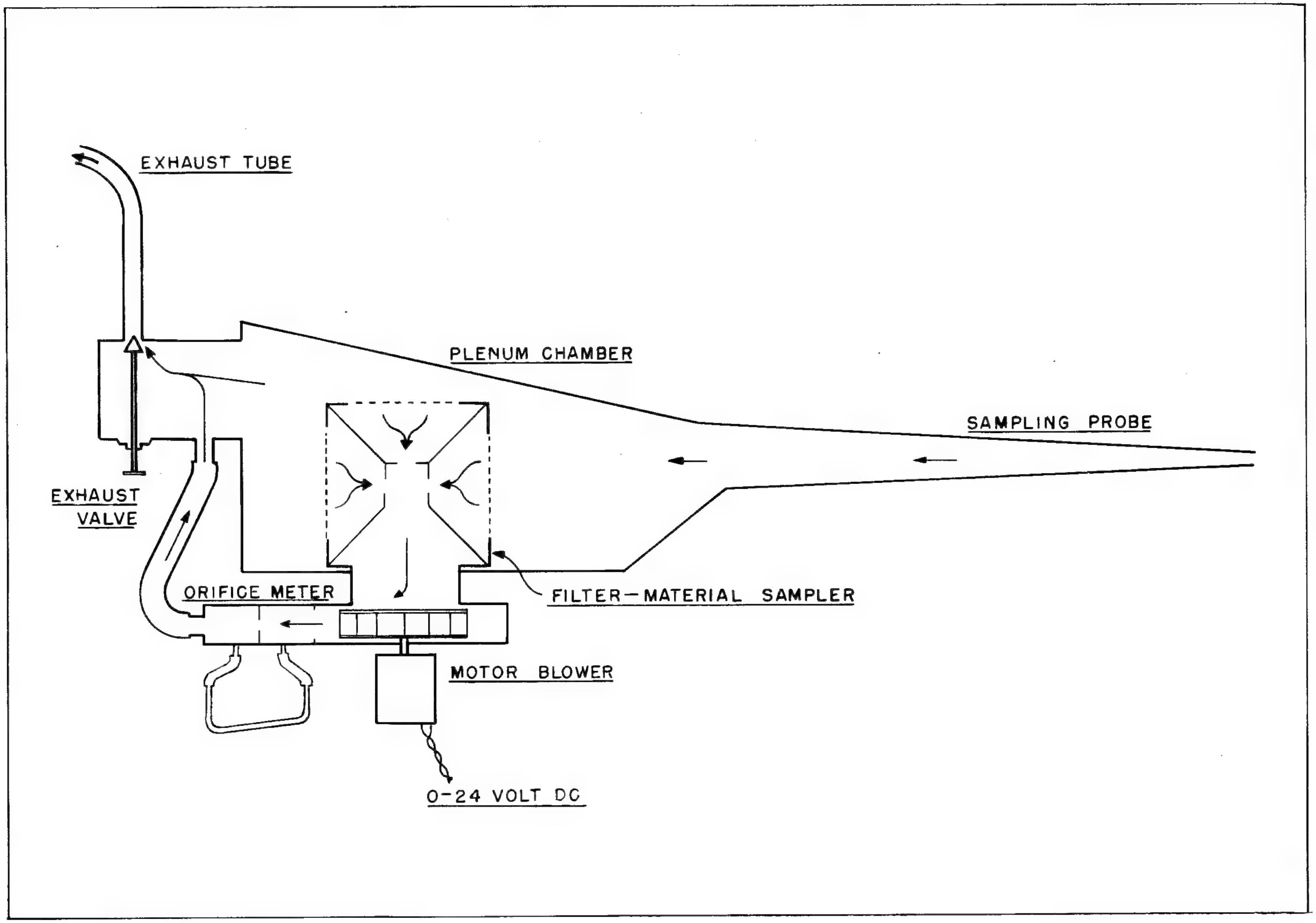

FIG. 2.5 Diagrammatic Layout of Sampling and Evaluation System Showing Direction of Air Flow

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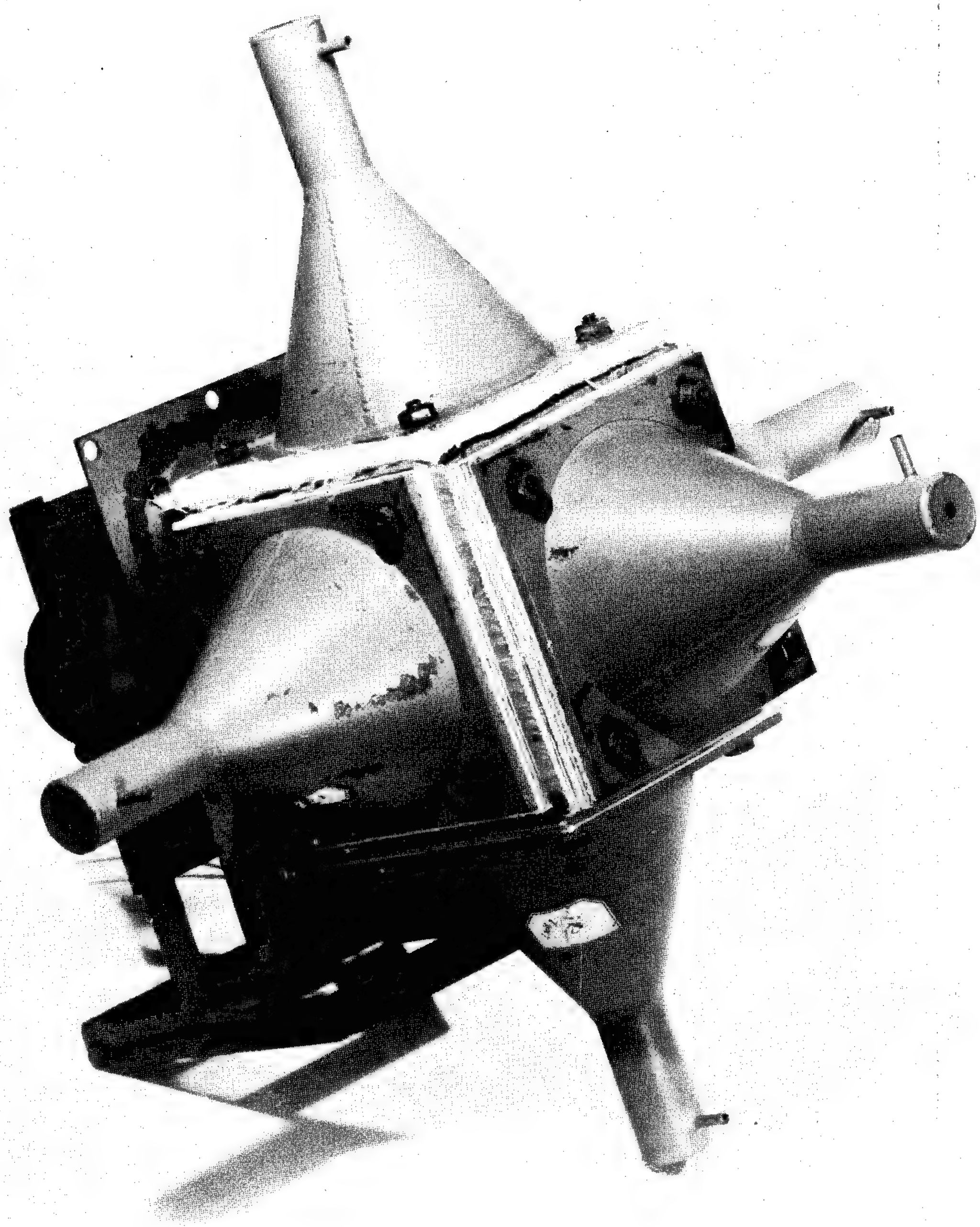

Fig. 2.6 Calibration Apparatus

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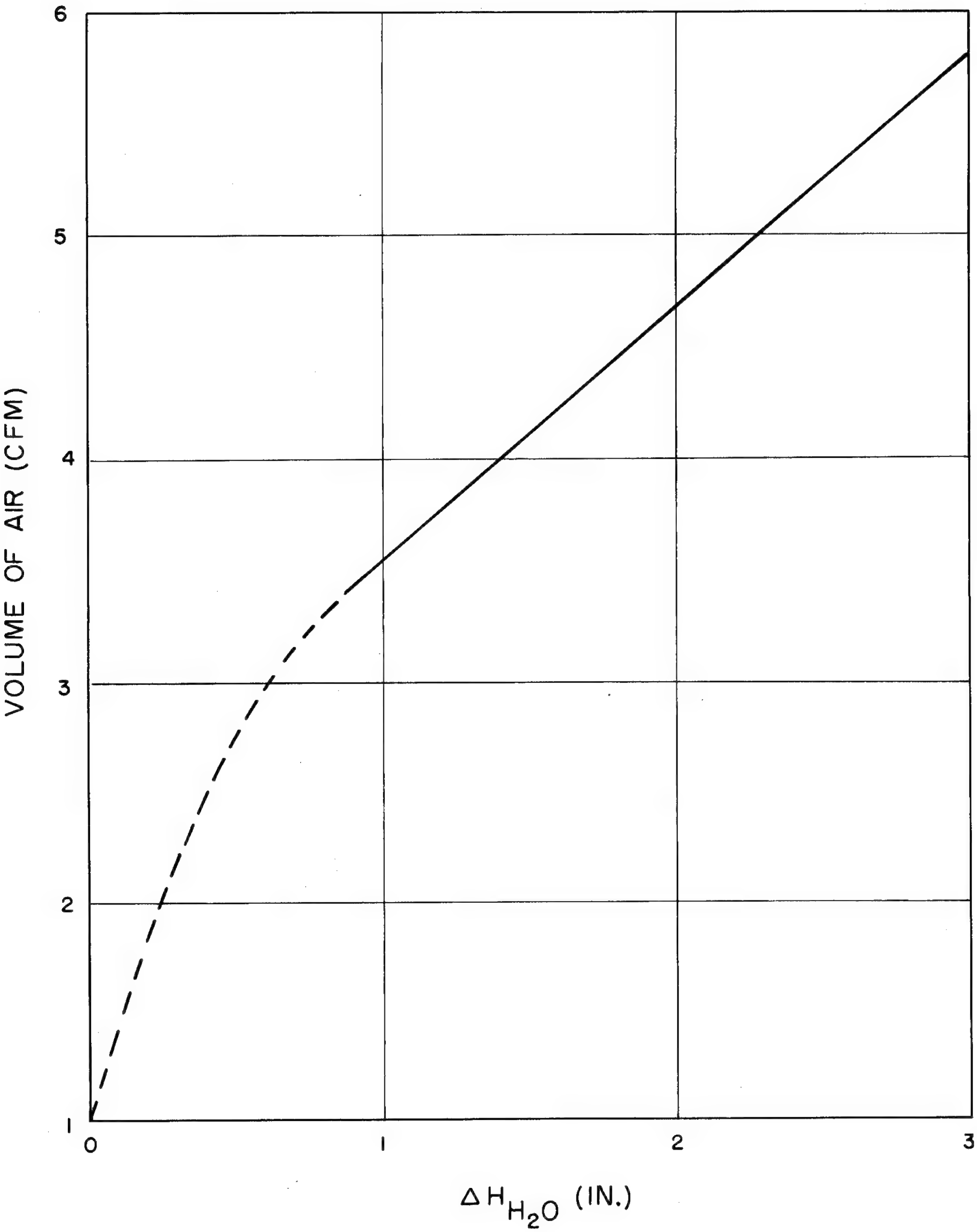

FIG. 3.1 Calibration of Filter Material Sampler Orifice Meter

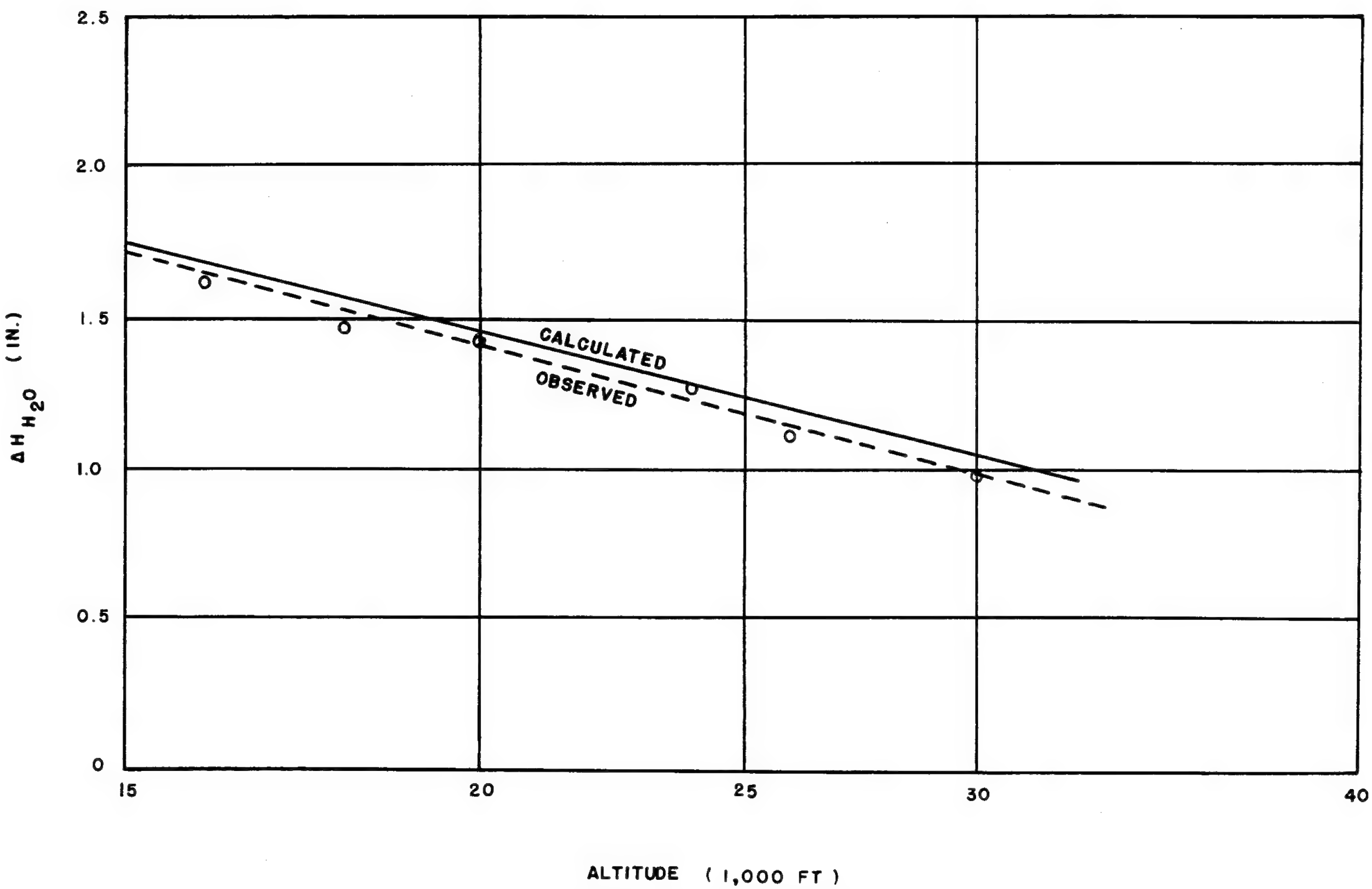

FIG. 3.2 Calibration of Flow Rate vs Altitude

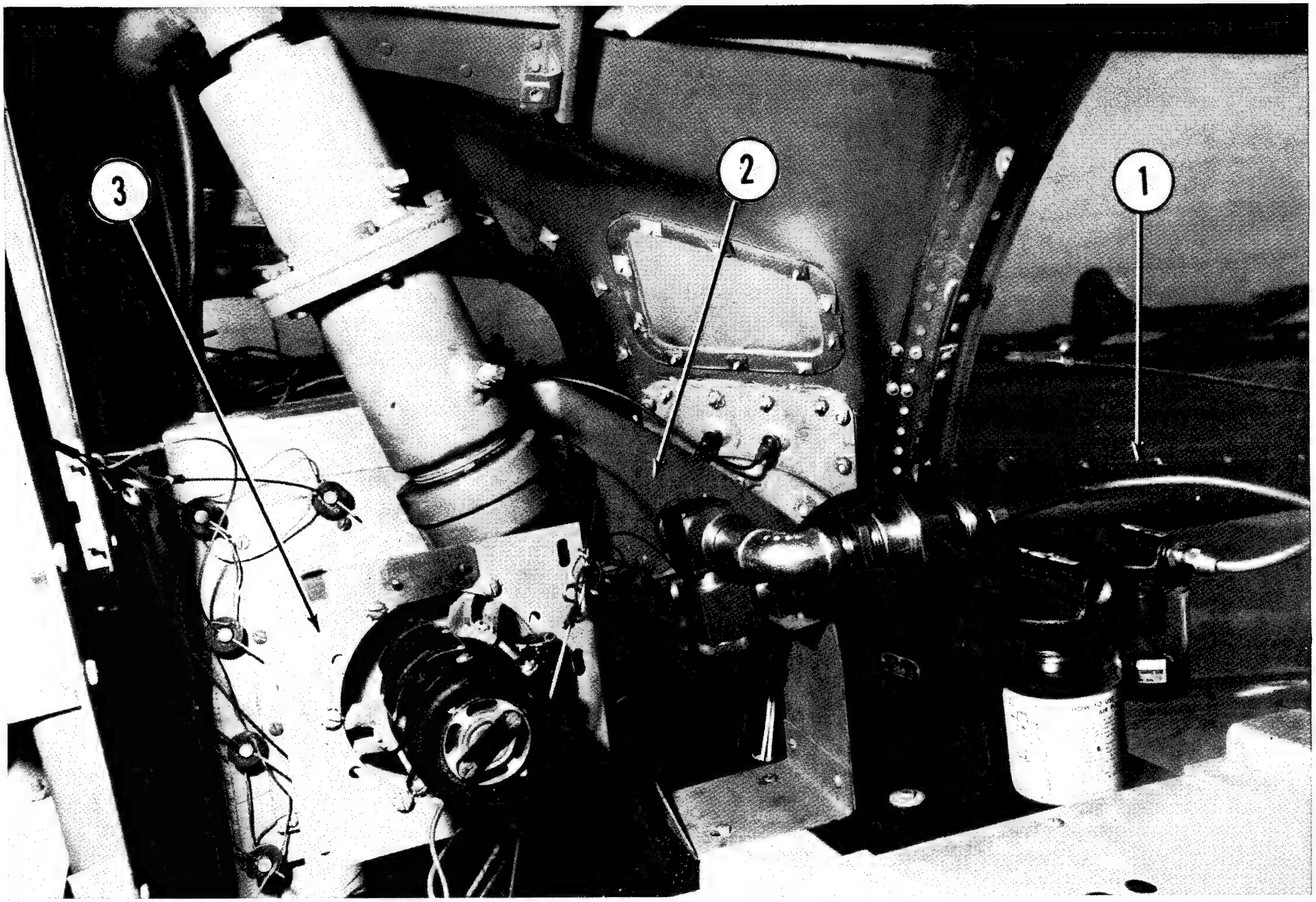

FIG. 3.3 Plenum Chamber and Filter Material Sampler Installation: (1) Probe; (2) Plenum Chamber; (3) Filter Material Sampler

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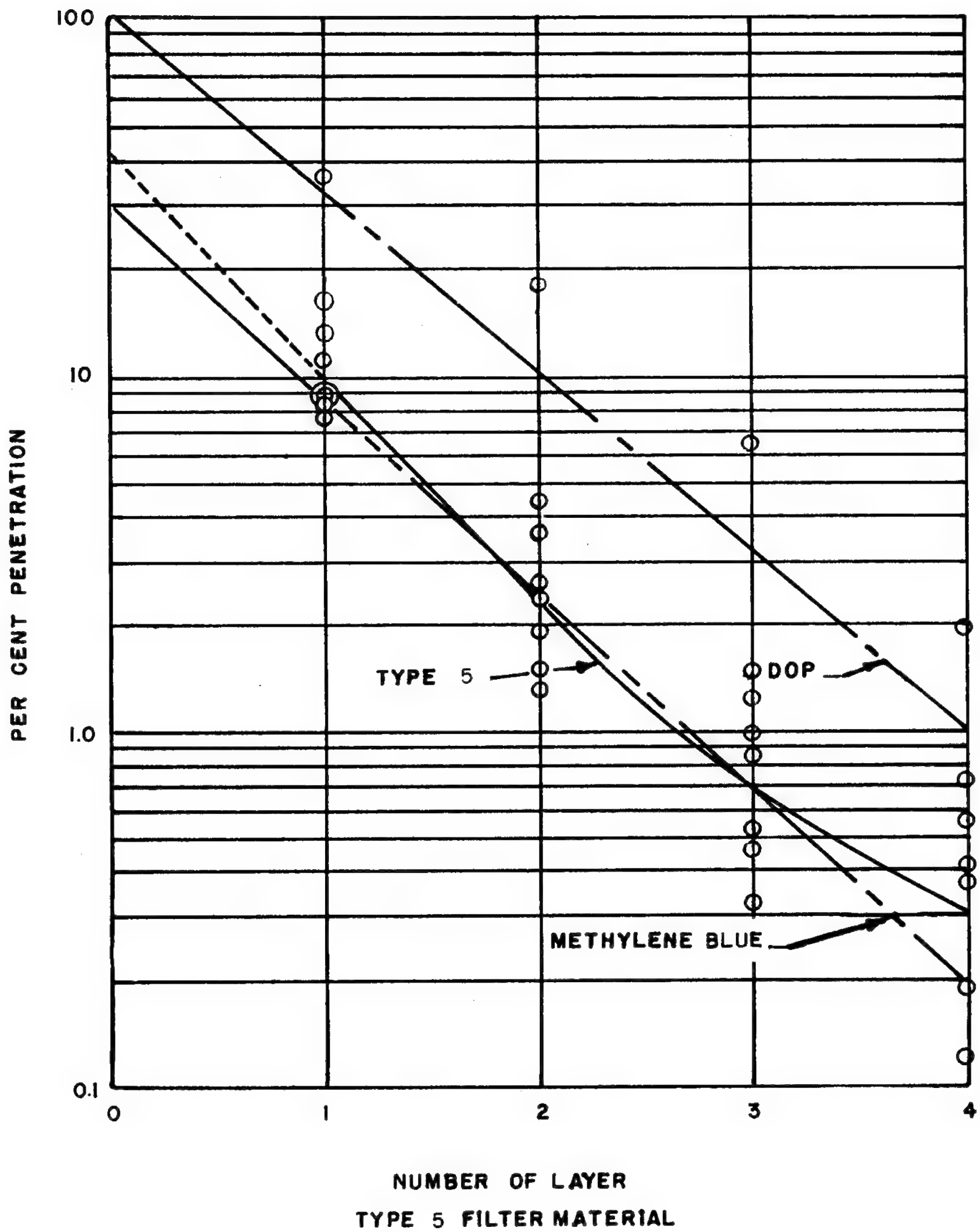

FIG. 4.1 Per Cent Penetration, Type 5, Dog Shot

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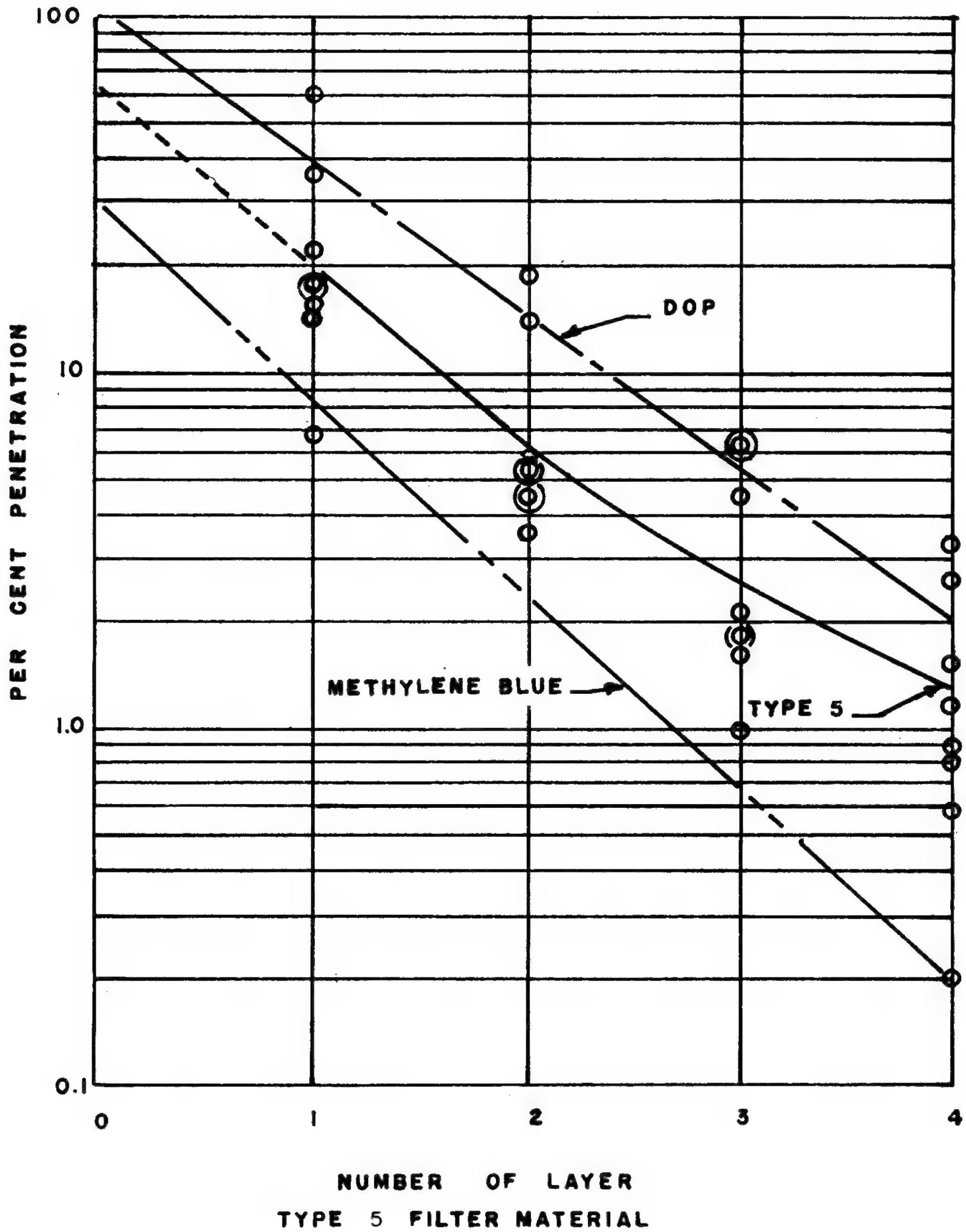

FIG. 4.2 Per Cent Penetration, Type 5, Easy Shot

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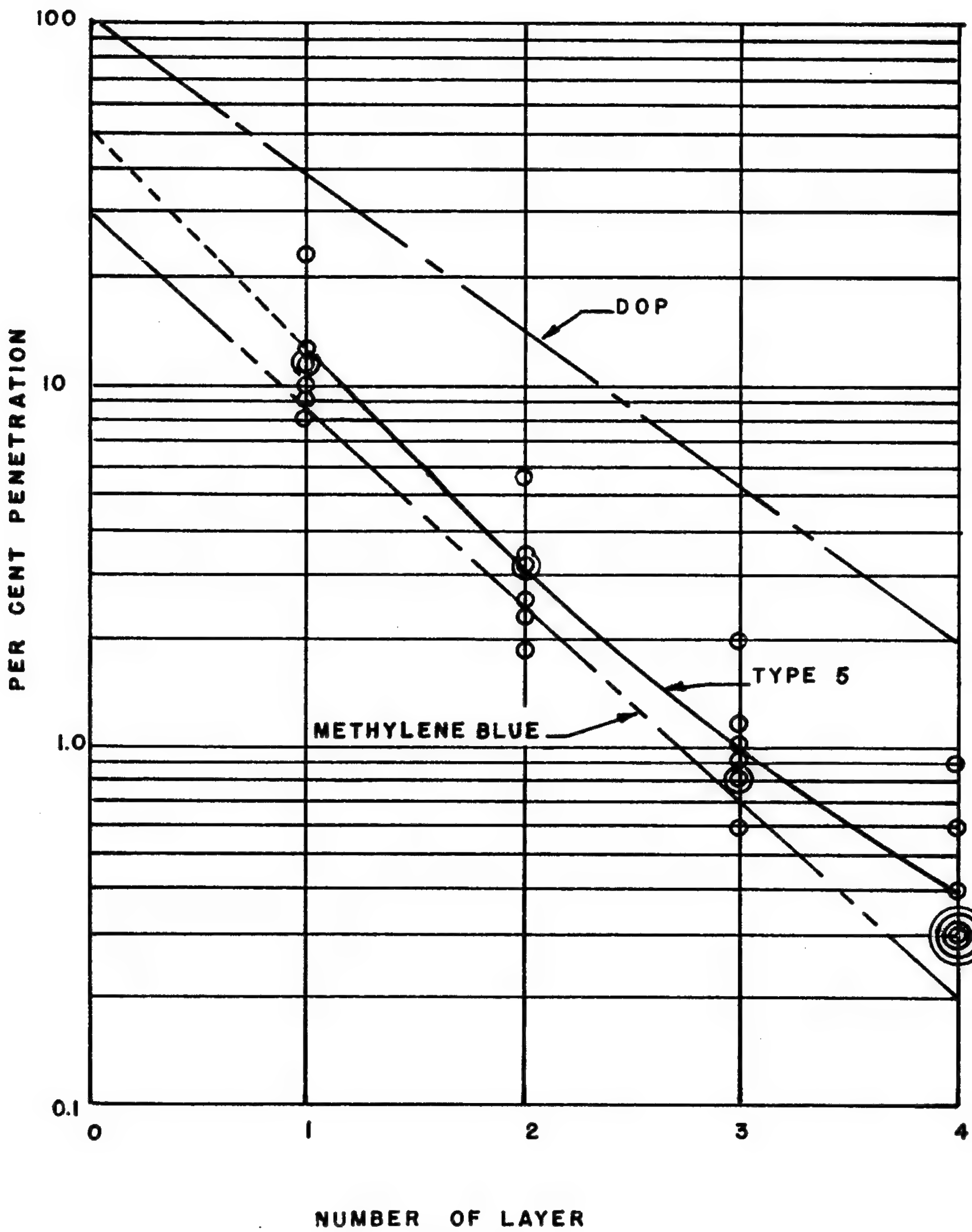

TYPE 5 FILTER MATERIAL

FIG. 4.3 Per Cent Penetration, Type 5, George Shot

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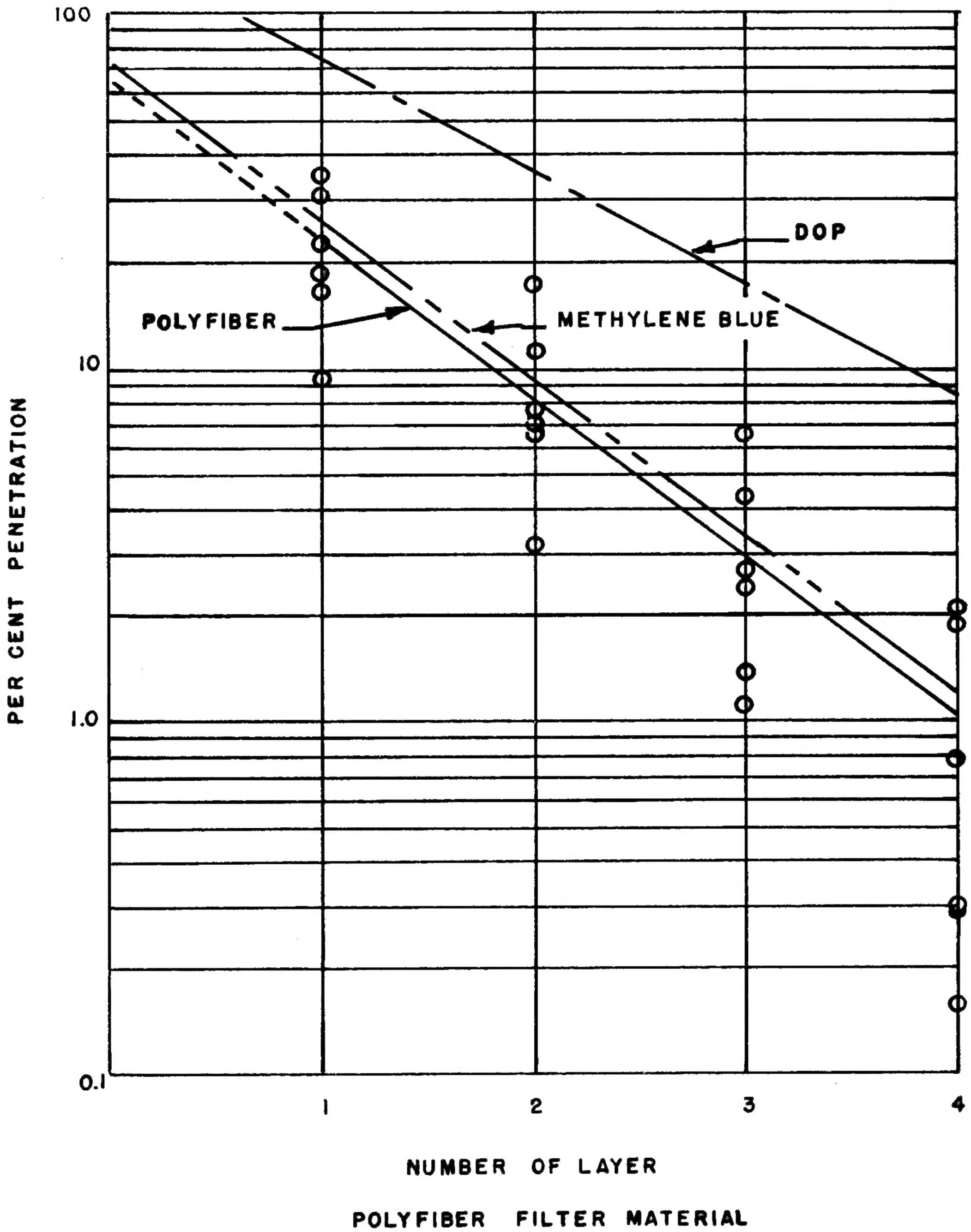

FIG. 4.4 Per Cent Penetration, Polyfiber, Dog Shot

[redacted]

[redacted]

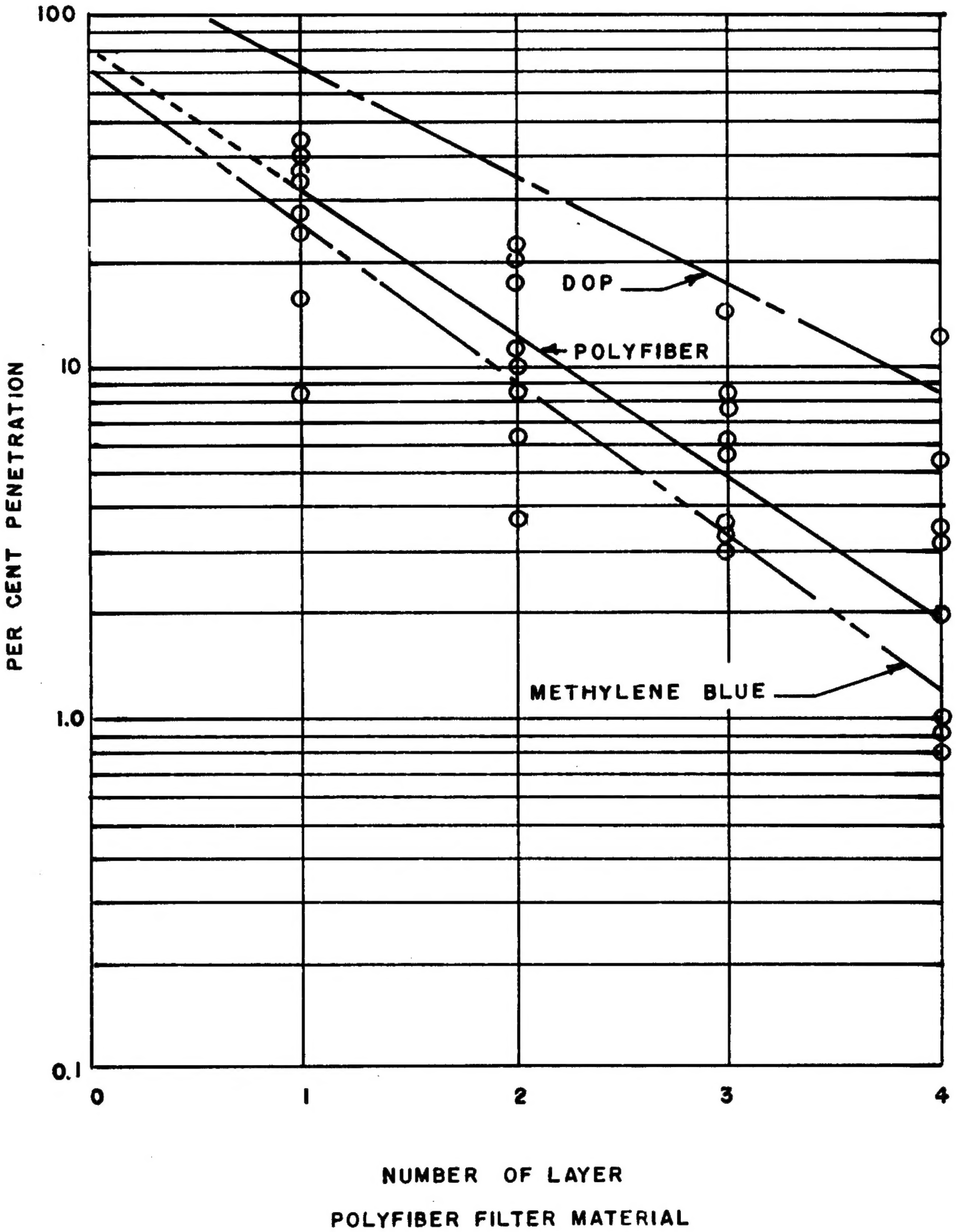

FIG. 4.5 Per Cent Penetration, Polyfiber, Easy Shot

[redacted]

[redacted]

UNCLASSIFIED

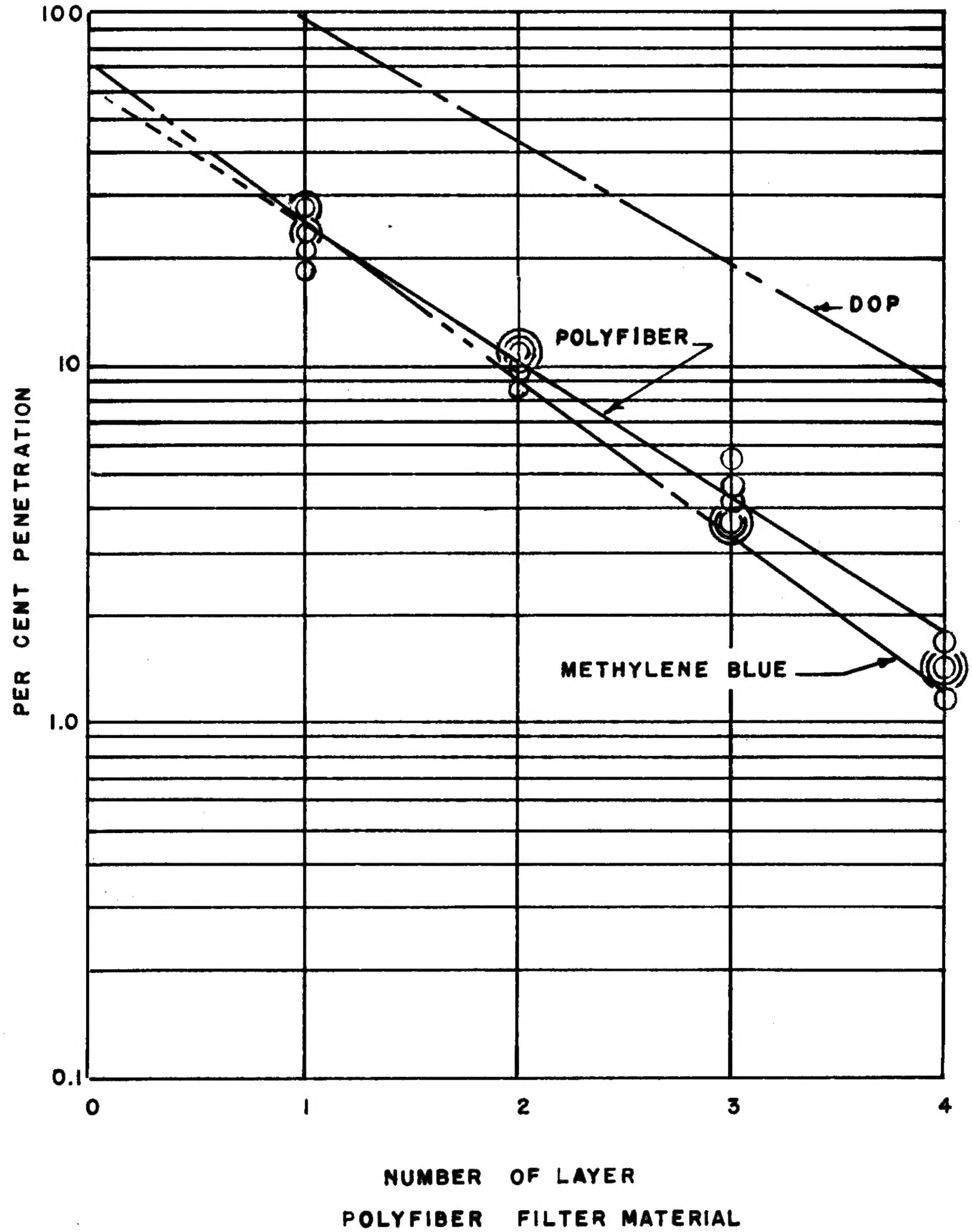

FIG. 4.6 Per Cent Penetration, Polyfiber, George Shot

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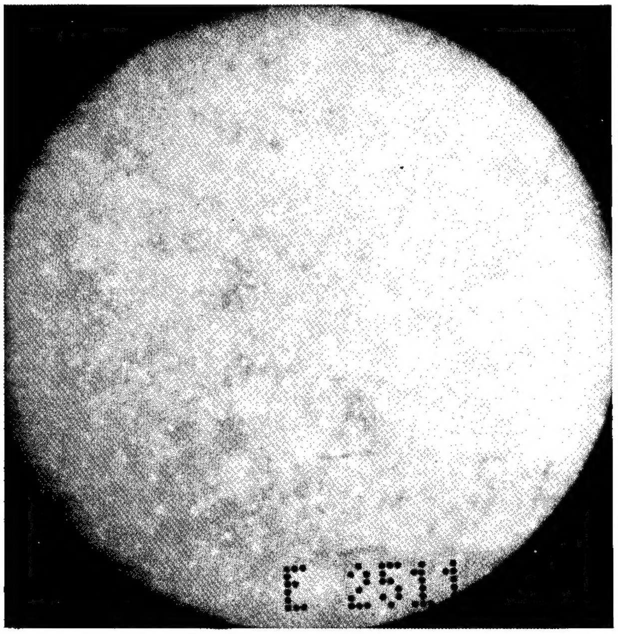
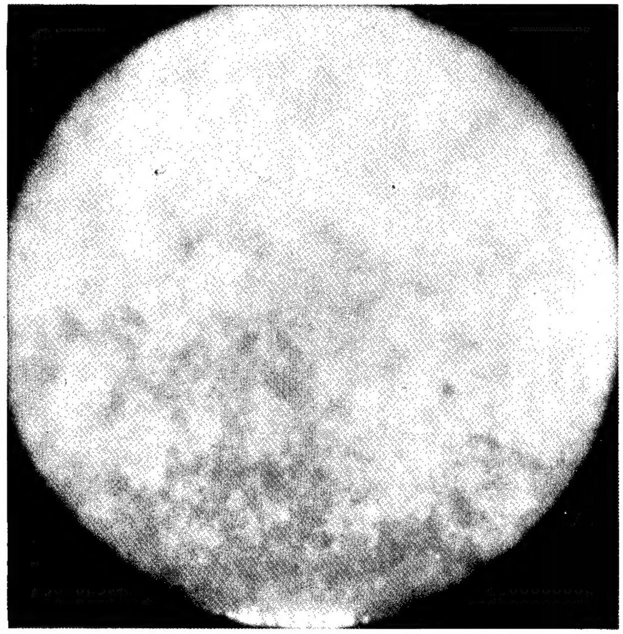
[redacted]

[redacted]

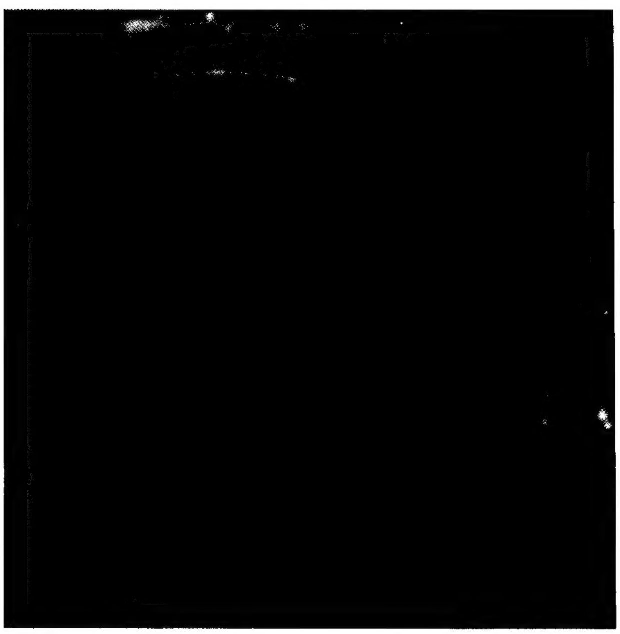
UNCLASSIFIED



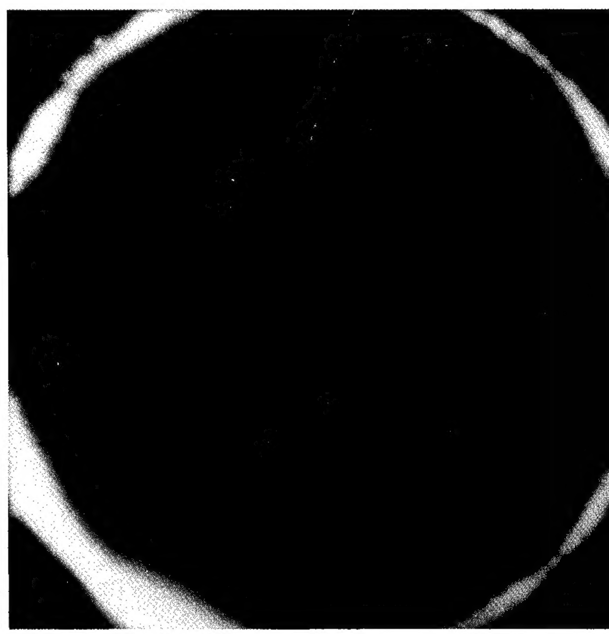
Satisfactory Sample
Exposure Time, 70 hr



Minor Rim Leakage
Exposure Time, 33 days



Minor Rim and Edge Leakage
Exposure Time, 34 days



Pronounced Rim Leakage
Exposure Time, 34 days

FIG. 4.7 Examples of Typical Radioautographs

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